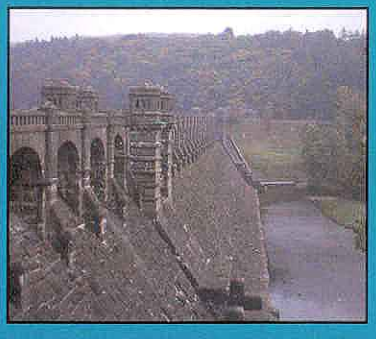


Institute of Hydrology

Annual Report 1994-95

Centre for Ecology & Hydrology

Natural Environment Research Council

Report of the Institute of Hydrology 1994-95

Natural Environment Research Council

Foreword

The terrestrial and freshwater sciences are a diverse and complex area covering a wide range of scales in space and time. There is also a strong interaction between them and the economic and social sciences, industry and commerce. It is increasingly recognised that many of the long standing and the newly emerging environmental issues require a multi-disciplinary integrated research for their resolution. The 1993 White Paper "Realising our Potential - a Strategy for Science, Engineering and Technology", reaffirmed the NERC as the lead body for research, survey and training in the environmental sciences and provided the NERC with a new Charter. To meet its aims Professor John Krebs, the Chief Executive, working with the Council, restructured the NERC. A major element of this was the regrouping within the **Centre for Ecology and Hydrology** of the

Institute of Freshwater Ecology (IFE)
Institute of Hydrology (IH)
Institute of Terrestrial Ecology (ITE) and the
Institute of Virology and Environmental Microbiology (IVEM)

The combined activities of the Institutes cover the full range of terrestrial and freshwater sciences and this must give CEH internationally one of the strongest capabilities for holistic research, environmental monitoring and as a data resource. The CEH outreach is extensive. The two figures in an Annex to this Report show the location of the principal CEH Institute stations in the UK and in those overseas countries in which CEH scientists are, or have been recently, active.

As the former Director of the **Institute of Hydrology** it is inevitable that I take a special interest in its activities. I ended my valedictory report as Director IH in 1993/94 with the message that I was leaving the Institute "in the safe hands" of Tony Debney. This has indeed proved to be the case. This Report demonstrates very well how the Institute's science has continued to flourish, that Commissioned Research has been maintained at a steady level and a number of new initiatives have been started. I commend the Report to you.

I would also take this opportunity to draw your attention to the complementary Annual Reports for 1994/95 from the other CEH Institutes and to the CEH overview report.

Brian Wilkinson
Director, Centre for Ecology and Hydrology

Contents

Director's Introduction

Engineering Hydrology
- Forecasting and design prediction: contrasting features of floods research
- HYREX: HYdrological Radar EXperiment
- Modelling global water scarcity
- Hydro-ecological modelling: a basis for river management
- Rainfall frequency analysis of drought severity

Information Hydrology 13
- The Rivers Data Centre 14
- A flood risk map for England and Wales 16
- Is the past still the key to the future? 18
- Entering the Internet and CD-ROM design era 20
- Exploring the World Wide Web 21
- The Library service 22
- IAHS Press 22
- Information Services 23

Hydrological Processes 25
- What are hydrological processes ? 25
- Global change and forecasting 27
- Hydrological processes in complex vegetation 28
- Sustainable natural resource management 31
- Satellite radar for soil moisture monitoring 32

Environmental Hydrology 35
- Regional water quality 35
- Water resource management in Nepal 38
- Hydrological and environmental impact of earthworm depletion by the New Zealand flatworm 39
- Predicting bacterial water quality 40

Land-use and Experimental Hydrology 43
- Modelling evaporative losses in the UK uplands 43
- Interception losses from immature forest in northern England 46
- Sediment transport research: high magnitude floods in the Yorkshire rivers 47
- Upland wetlands, climate and water quality in Wales 49
- Improved drilling capability for difficult terrain 51

Appendix I: Staff List 55
Appendix II: Publications, Reports and Software 59
Appendix III: List of Research Projects 68
Appendix IV: Finance 70
Appendix V: Location of CEH Institutes and Research Contacts 71

Director's Introduction

Water is different: it cuts across all facets of society and therefore has no favoured user community.

The 1993 Government White Paper "Realising Our Potential" precipitated an unprecedented examination of the way science, engineering and technology links with national endeavour and contributes to prosperity and to the quality of our lives. 1994/95 has therefore been a year with more attention paid to the way our scientific community organises, plans and executes delivery of its research than at any other time since the formation of NERC. Some changes have already occurred. Others, concerned with the planning and content of future research portfolios and funding mechanisms, are still emerging.

Key events in which we have actively participated include:

- Efficiency Scrutiny of Public Sector Research Establishments.
- The reshaping of NERC management structure with IH moving into a Centre for Ecology and Hydrology.
- Identification of key environmental issues and strategic aims within the new NERC Mission.
- Development of the National Technology Foresight Programme and NERC's own foresight activities.

This report therefore records a selection of items from our research portfolio against a background of rapid evolution and adaptation responding to a national drive to improve the relevance and transfer of science from the research base to users. This is, and has been for two decades, an area in which we excel. 160 projects during the year concerned research of direct benefit to users, many of them making advances on previous work emerging from our strategic core programmes, or as a consequence of requests to continue or expand work funded by users in the past.

Output from the Institute has increased again in 1994: 199 research reports were delivered to users whilst 150 scientific papers were published in the scientific literature.

Scientific priorities

NERC has a revised Charter and, in responding to its new mission, recognises six major issues high on the UK's environmental agenda:

(1) Management of land, water and the coastal zone, identification and exploitation of land and freshwater resources and their sustainability.

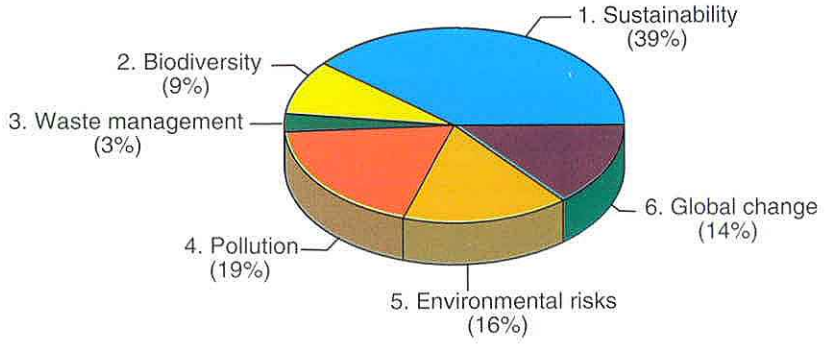
(2) Understanding and protection of biodiversity.

(3) Waste management, bioremediation and land restoration.

(4) Pollution of air, land and fresh water in relation to environmental and human health.

(5) Environmental risks and hazards and improved prediction of extreme events.

(6) Global change, including prediction on a range of time and space scales.



Number of research projects expressed as a percentage of the total programme

Key problems in basic understanding within the areas of these priority issues will lie at the heart of NERC's future science agenda. Most of our work already addresses these matters.

About 40 per cent of current work relates to NERC Issue 1. Our research focuses on improved understanding of the impact of land-use and other anthropogenic changes on freshwater systems, on a better understanding of the physical processes in the terrestrial hydrological cycle and on the ability to model — and hence predict — the impact of human activities on this cycle. Here the long-term aim is to provide substantial support to the development of sustainable management techniques, and increasingly, to encompass the challenge of managing complete river basins.

50 per cent of our projects address Pollution, Environmental Risk and Global Change (NERC issues 4, 5 and 6) in more or less equal proportion as follows:

- Improved understanding of the dynamics and key processes controlling pollution, through surface water systems and their representation within mathematical models which aid scientific understanding and hence water quality management. (Issue 4)

- Advancing the science of predicting and forecasting the extremes of hydrological and meteorological variables, and to develop and apply hydrological models to improve the effectiveness of engineering provision for water resource and flood management. (Issue 5)

- Increased understanding of hydrological processes at

regional and global scales; to foster improved representation in models of the global climate and in continental-scale hydrological models of future climate and regional water resources. (Issue 6)

Our current involvement in research aimed at understanding and predicting biodiversity is relatively small. However, placing this Institute within a Centre for Ecology and Hydrology has strengthened and encouraged opportunities for hydrological science to contribute more to the understanding of biological processes and interactions and hence a fuller appreciation of the role of water as an environmental agent. IH brings to this new venture established research experience on the effects of vegetation and soil processes on the hydrological cycle in different climates; the development and application of hydro-ecological models; and sustainable use of water, particularly where the resource is sparse and especially where dryland degradation is a concern.

Research focused *directly* on waste management science has not been an area of major involvement for this Institute. Instead we have concentrated on the processes and mechanisms by which pollutants, chemicals and sediments are transferred from the land surface and soil into fluvial systems and on quantifying fluxes in river systems. We bring to CEH extensive experience in the development and application of mathematical models in this area and I recognise many opportunities to work closely with the three CEH sister institutes on in-river processes, reclamation of polluted land and in bioremediation of surface waters.

Delivery mechanisms

CEH is now the route for NERC funding of our core science programme and indeed for research targeting specific strategic objectives identified through NERC planning exercises. Core science funding for IH in 1994/95 continued to be held at about £1 million and I am delighted to record funding for Community Research Programmes (thematic activities) at almost the same level. Together they now comprise some 30 per cent of our income which is invested almost entirely in specific research activities or in direct scientific support to these.

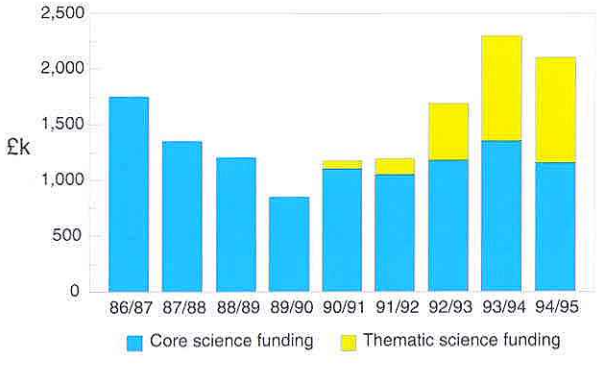
Our current science budget programme comprises 28 projects.

- A portfolio of relatively short duration (3-year) projects. These address key scientific problems of relevance to matters of emerging strategic concern. Organics in aquatic environments, effects of UK forestry on summer river flows, ecologically acceptable river flows and interactions between soil/vegetation/atmosphere and climate are examples of current work in this category.

- Long-term intensive monitoring of small experimental catchments to improve the prediction of effects of land use, land-use change and climate on water yield and quality in the UK. Here our Plynlimon laboratory has delivered the most important hydrological experimental record in Europe, arguably one of the most comprehensive in the world. The UK water industry, researchers from around the world and many student parties visit each year. Currently the site supports seven CASE studentships, several dissertation projects and is the location for several joint research projects with other NERC Institutes.

- Development of new techniques and facilities which underpin our science base. Currently these include research to measure regional evaporation from satellite data, exploiting remote sensing applications for hydrology, linking hydrological and hydrochemical models and GIS systems, and researching new data capture techniques.

- Our single largest Science Budget expenditure concerns the UK Surface Water Archive. Stewardship transferred to IH in 1982 to deliver Government's requirements for a central archive alongside that of the British Geological Survey Groundwater records. Data from a network of over 1200 river gauging stations are collated. We publish yearbooks and specialist reports dealing with



the analysis of significant hydrological events. During the winter of 1994/95 the archive was a major source of advice to Government as severe flooding threatened. As I write it is now providing urgent analysis of the deepening drought.

Nineteen projects have been funded under NERC's Community Research and Special Topic programmes. This year's annual report highlights emerging results from our participation in the Land Ocean Interaction Study (LOIS). IH has made excellent and rapid progress in running the Rivers Data Centre and in setting up core chemistry and coordinating modelling activities.

At the heart of reorganisation is a drive towards increasing efficiency to compete more effectively, and a push to encourage the scientific community to be more aware and hence more responsive to the needs of users of the results of research. It is difficult for this Institute to envisage closer associations with users than have existed throughout the past two decades. This has been possible because water is a special natural resource and hydrological research touches and benefits virtually every segment of human activity and most facets of the natural environment. Each and every user competes with others for the resource, affecting the quantity and quality as often as not to the disbenefit of other potential users somewhere else within human society, or indeed to the disbenefit of other life forms attempting to co-exist with man.

IH has established an enviable reputation for providing impartial and expert advice, across often conflicting responsibilities of many of the UK organisations with statutory, professional, industrial or commercial interests in water. 1994/95 saw associations with some 40 private sector companies. This has given both depth and breadth to the range of topics and environmental issues in which we are actively involved and continues to attract a wide range of users: about 60% of income was derived from such commissioned research in 1994/95. Important examples are:

Flood extremes
- the analysis of specific floods
- statistical methods of flood estimation and rainfall frequency
- flood runoff in urban areas
- real time flood forecasting techniques
- mapping of flood-risk areas
- initial work on the Flood Estimation Handbook
- catchment characteristics for flood estimation

Water quality
- critical loads
- acidification trends
- herbicide degradation
- impact of forest management

Water resources and water supply
- soil moisture monitoring
- regional procedures for estimating groundwater recharge

Riverine/wetland habitats
- ecologically acceptable flows
- design of habitat improvements
- protection of wetlands in East Anglia

Environmental impact
- impact of agricultural reforms and climate change on runoff in major basins
- impact of waste disposal and mineral extraction

Some of our work supports the aid programmes of the Overseas Development Administration (ODA) or contributes to invisible earnings from the export of UK know-how overseas.

- Small-scale irrigation and water management for sustainability in semi-arid areas.
- Establishing design methods for urban drainage in developing countries.
- Providing impartial advice to the governments of Lesotho and Republic of South Africa to calculate water transfer royalties.
- Investigation of low flows in Southern Africa.
- Yield assessments of reservoirs in Tanzania.
- River basin management in Chile.
- Groundwater modelling in Jordan.
- Development of improved methods and procedures for irrigation systems in the Philippines.

Encouraging technology transfer and public understanding of the environment

Professional responsibilities of IH staff are very wide, representing NERC on some 30 national committees, including Government Advisory committees, the British Standards Institute, professional societies and institutions, and on seven Research Council committees. Staff also continued to contribute their hydrological expertise to 25 European and other international committees and working groups and to the editorial boards of various international journals.

The Schools Liaison Officer has co-ordinated activities with local schools. During the year nine placements were found for work experience students and we had our first GNVQ student on site. For SET95, a study pack comparing the hydrology of a Chalk and a non-Chalk catchment was produced and circulated to local schools and a hydrological essay competition held.

Working with users however provides the main route for transfer of our science. The application of Information Technology in the form of software development (including models), database services and remote sensing applications are becoming increasingly important to us and the water industry. We welcome and are actively seeking closer collaborations. The main industrial and commercial users in 1994/95, apart from the water industry itself, included:

- chemical industry
- power sector
- civil engineering companies
- peat and mineral aggregates industry
- waste disposal companies
- agricultural sector
- insurance and finance sectors
- environmental consultancies

A 'Software Open Day' to demonstrate our increasing range of hydrological software was held at Wallingford in January 1995. Spread over two days, this was attended by over 100 representatives from universities, the water industry and consulting firms.

In conclusion

When I was appointed Acting Director in April 1994 I replaced Professor Brian Wilkinson who moved to take on the challenge as NERC's first Director of the Centre for Ecology and Hydrology. I inherited an Institute in very sound health. We deliver one of the nine environmental disciplinary responsibilities of the NERC Mission. We comprise just six per cent of NERC staff but seem exceptionally well placed to help it meet its future. We have yielded 13 per cent of its externally supported research and are already major players in areas of its future priorities.

1994/95 was not an easy year for my staff. Increased competitiveness in science involves additional overhead duties. Preparation of bids and submissions to win funding is an activity of ever increasing significance to all researchers. Last year the time just to this activity doubled and amounted to eight man-years effort in a community of 190. Internally one of our measures of efficiency is the delivery of at least 70 per cent of all our income directly to scientific activities. This we managed, just, and I must record my thanks to all staff for their continued high level of performance against the background of considerable change and of growing expectations on them.

Finally, perhaps a comment on one change that will be particularly welcome, especially to IH staff at Wallingford, but also to those colleagues from the British Geological Survey and NERC Computing Services who share this site with us. The 1995 NERC Business Plan shows funding for replacement over the next two years of temporary accommodation and for improvements to library, data centre and meeting room facilities. These have been planned for and awaited over almost a decade during which hydrological and hydrological research at Wallingford has flourished and grown. Now as the directorate of the Centre for Ecology and Hydrology also moves onto this campus, accommodation becomes an ever more pressing issue which can only be solved by even more temporary buildings. It will therefore be increasingly difficult for us to welcome students and visiting researchers to work here over the next two years. I hope that staff and our user community will bear with us until a permanent solution has been provided.

Tony Debney, Director

Extreme hydrological events inevitably raise many questions in our user community concerning frequency of the event, likelihood of recurrence, whether or not frequencies are changing and could the event have been forecast? The engineering community of the water industry, the resource planner responsible for the design, management and operation of complex and costly water resource systems and UK government departments are all users of much of this research.

Engineering Hydrology

Our research seeks to provide advanced techniques for flood and low flow estimation, for forecasting extremes, for assessing the availability of water resources and increasingly for determining the impact of environmental change on the reliability of existing and proposed schemes. A selection of key issues and scientific achievements is described in the following pages. Additionally, we continue to advance modelling of the inter-site and inter-duration dependence in extreme rainfall, assessing the impact of urbanisation on flood response in monsoon climates and regionalising hydrological variables based on extensive international databases. Our achievements would not have been possible without the close and long-term co-operation that we have established with national and international funding agencies, consulting companies and university departments throughout Europe and the rest of the world.

FORECASTING AND DESIGN PREDICTION: CONTRASTING FEATURES OF FLOODS RESEARCH

Duncan Reed and Bob Moore

In some settings, flooding can bring riches as well as hardship. But in developed countries the impact is nearly all for ill: flooding endangers, destroys, damages and disrupts. The Great Flood of 1993 in the USA killed 48 people whilst damage costs are estimated to be as great as $15-20 billion with 50,000 homes affected. Though flood depth determines the extent of damage, particular danger arises from flash floods, through their swift onset and accompanying high velocities. While the sustained Rhine flood of January 1995 verged on a European catastrophe, the Vaison la Romaine event in Southern France in September 1992 was the more costly in human terms, when 40 people perished within hours of rain commencing.

Floods research has always formed an important element of the Institute's work. In this brief overview, we identify features that distinguish flood estimation and flood forecasting, and point to some current lines of research.

Flood estimation is crucial to the cost-effective design of sewers, culverts, dykes and other structures, designed to accommodate flood flows safely. It may also be relevant to setting insurance premiums, through the production of flood risk maps (see also page 16). *Flood forecasting* is vital to raising the alarm when defence-threatening conditions arise. Timely warnings allow the flood to be fought, keeping the water away from property and people or *vice versa*.

For some people, professional duty or natural curiosity is a spur to understanding in the aftermath of a major flood. To others, the flood phenomenon is introduced in the lecture room, with the analysis of flood peak data, or rainfall-runoff modelling of recorded events, soon following. The modelling of flood formation on instrumented catchments provides much scope for statistical, mathematical, conceptual and physical elaboration.

Such experimentation affords opportunities to identify and quantify the influential processes. An important aspect is to represent the effects that particular changes in land use exert on flow regimes. Yet the derivation of improved catchment models does not dominate current IH research in flood estimation and flood forecasting. Perhaps this reflects that in these very practical areas of engineering hydrology *risk assessment* is more important than modelling *per se*. Statistical aspects are therefore never far away.

Contrasts

Flood estimation is inevitably rather nebulous and long-term, the user thinking as much of hypothetical "design" events as real ones. A recurrent worry is that the subject catchment may somehow be unusual, and that rare floods might be rather greater than standard assessments indicate. There are few opportunities for feedback in flood frequency estimation. A good estimate may be blackened by the chance incidence of extreme events. More likely, a poor estimate may be sustained for many years, perhaps because relevant data for validation are never gathered.

In contrast, flood forecasting is both short-term and exceedingly specific: so specific that being up-to-the-minute may take precedence over being completely right. Here the fear is that the current *event* may somehow be unusual: if the incident rainfall is unusually distributed in time or space, might this mislead the forecast? A feature of flood forecasting is that opportunities for feedback arise when they are most needed: a warning is issued and, within hours, further knowledge of the forecasting system's performance is gained. Updating methods, which combine a model forecast with recent measurements of river flow, allow forecasts to be refined.

Real-time flood forecasting

What are the priority issues that flood forecasting research must address and how are they to be advanced? These questions were at the heart of a recent review of opportunities for research carried out for the Ministry of Agriculture Fisheries and Food. Of eight topics identified, greatest priority was attached to "flood warning under uncertainty" and "updating methods". With regard to forecasting in the presence of uncertainty, the *ensemble* approach is being developed in which the decision to warn (or not) is based on synthesis of a number of equi-probable outcomes to the current event.

Research on updating procedures is exploring methods suggested by recent developments in Bayesian statistics, in which complicated manipulations of probability distributions are replaced by use of appropriately generated random samples. In principle, these allow an optimal solution to the updating problem, while avoiding the approximations and assumptions encountered in use of the much researched Kalman filter.

Snow and snowmelt present special difficulties when forecasting river flows. The processes involved are complex and the inputs difficult to specify, not least through spatial variability. A study for the National Rivers Authority and MAFF has set up enhanced instrumentation in the headwaters of the Tees, Aire, Severn and Tame, with the aim of providing a database to support snowmelt model development. The models being assessed have varying data requirements, and range from simple lumped models with a "temperature index" melt equation, through more distributed conceptual formulations employing digital terrain data and elevation zoning, to an "energy budget" description of melt under topographic control. The year saw the extension of the study to the Balquhidder catchment under Scottish Office support.

The variation of rainfall across a catchment is a further source of uncertainty in flood forecasts. Research on the measurement of rainfall by radar has been a feature for some years. Most recently, techniques for radar calibration using raingauges and radar rainfall

forecasting have been integrated to form the HYRAD (HYdrological RADar) system, a software product for the real-time reception and animated display of weather radar data as both raw images and processed products. Research on rainfall and radar is continuing as part of the HYREX Special Topic (see page 4).

Flood forecasting is often required across a region, drained by a number of river systems and monitored by telemetry outstations measuring river and tidal levels, rainfall, weather variables and control structure settings. Forecasting in such a complex situation concerns not only a range of catchment, channel flow routing, hydrodynamic and tidal models — through which data and forecasts are passed — but also the rigorous management of incoming data and outgoing forecasts and flood-warning messages. The River Flow Forecasting System (RFFS) accomplishes this in an efficient manner. Its generic design allows application to any river network without recoding, the easy adaptation of an existing configuration to accommodate new forecast or measurement sites, and a socket-style interface allowing new models to be introduced with ease. An operational system can make use of the observed and forecast rainfalls available from HYRAD. The RFFS is now used for forecasting throughout Yorkshire, in the Thames basin, the White Cart (Glasgow) and the Indus (Hong Kong).

Flood frequency estimation

Research to develop a new Flood Estimation Handbook began in April 1994. The Handbook will supersede the much used Flood Studies Report and supplementary methods. One part will provide a technical restatement of the FSR rainfall-runoff method which, following recent enhancement, will continue in use for some years yet. Other parts of the Flood Estimation Handbook will be original, presenting new generalisations of rainfall and flood frequency across the UK. Although funding is led by MAFF, the programme relies on funding and co-operation from many sources.

Users can look forward to an important change in flood frequency estimation by statistical methods: catchments will be grouped according to the similarity of their flood regime, *not* in geographical regions as previously. Particular emphasis is also being given to methods that exploit catchment information in digital form, freeing the user from routine map-work.*

A common concern is that extreme floods may arise through a combination of factors, perhaps heavy rainfall accompanying snowmelt, or an intense storm occurring when groundwater levels are unusually high in a normally unresponsive catchment. It can be difficult to represent these joint probability aspects within general procedures for flood frequency estimation. Following specialised studies with the University of Sheffield of a complex joint probability problem in reservoir flood safety, IH research has shifted to flood estimation at river confluences. If systematic rules can be devised for choosing tributary flows, while making good use of historical records, the current capability of hydrodynamic models — to represent complex river channel systems — will become much more relevant to flood design.

Continuous simulation modelling

In due course, more advanced catchment models or modelling techniques will again assume importance in floods research. Longer-term research is exploring the feasibility of basing flood frequency estimates on the statistical analysis of model outputs. This requires the development of catchment simulation models capable of operating continuously in time, coupled to extensive, spatially consistent, rainfall time-series, perhaps obtained by stochastic modelling of rainfall in time and space.

Integrated flood management

Best-practice flood management demands attention to both flood estimation and flood forecasting. Flood estimates are required to guide planning — especially of development on the flood plain — and, in design, to ensure that flood waters are evacuated with minimum damage to life and property. Flood forecasting and warning form a vital step in the flood management process to further alleviate damage. While the need for flood warning may arise where planning consent has been granted too liberally in the past, it also arises naturally in design, where a level of protection can be afforded above which flood warning provides the most cost-effective solution.

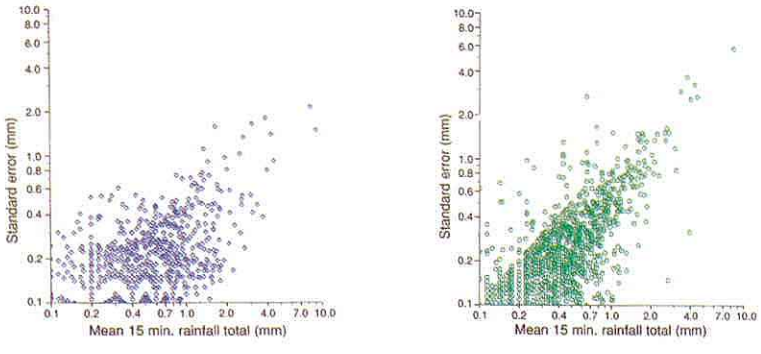
Whether flood protection or flood warning is the more natural response to severe flooding is for social historians to consider. Though somewhat irrational to the analyst, single events change perceptions and raise community desires for more protection. This applies in the UK no less than in major basins such as the Rhine and Mississippi. Until the next big one, floods research at IH continues to improve the methodology in both areas.

**Those wishing to register an interest in the new research can do so by writing to the Flood Estimation Handbook team at the Institute.*

HYREX: HYdrological Radar EXperiment

This community research investigation, funded by NERC under its Special Topic Programme, aims to advance hydrological science through gaining a better understanding of rainfall variability, as sensed by weather radar, and how this variability impacts on flow regimes at the catchment scale. Six research projects are in hand, based at the universities of London (Imperial and University Colleges), Newcastle, Reading and Salford, together with IH, ranging from improved precipitation measurement using polarisation and vertical pointing radars, through network design of radar/raingauge networks and spatial-temporal modelling of rainfall fields, to rainfall forecasting based on stochastic and meteorological concepts.

An important focus to the project is a set of shared experimental facilities centred on the Brue catchment in Somerset, south-west England. This comprises a network of some 50 recording raingauges over the 132 km^2 catchment, with flows gauged at Lovington and scanned by three radars: a new Doppler C-band radar at Cobbacombe Cross, a conventional C-band radar at Wardon Hill and an experimental Doppler dual-polarisation S-band radar at Chilbolton. Additional facilities include a mobile vertical-pointing X-band radar, a line network of rapid response raingauges aligned from Chilbolton towards the Brue, automatic weather and soil moisture stations, a disdrometer, radiosonde ascents from various locations and access to the Met. Office Research Flight. Support for this infrastructure comes from the National Rivers Authority, the Met. Office, the Ministry of Agriculture Fisheries and Food and the water utilities.



Empirical relationship between rainfall sensor accuracy and rainfall magnitude:
Single raingauge (left) and Wardon Hill radar (right)

Design of radar/raingauge networks for hydrological use

IH is reviewing the requirements for rainfall field estimates in the hydrological sciences to establish how these can be best met using networks of radars and raingauges. The data collected are subject to statistical analysis and physical interpretation to understand (i) the accuracy of different sensors to measure rainfall and (ii) the sensitivity of catchment flow models to rainfall uncertainty and variability.

An initial step in the project was the design of the raingauge network itself which now comprises 22 gauges at the centre of 2 km radar grid squares, two SW-NE lines of four squares each containing two gauges and two squares having dense networks of eight gauges in areas of low and high relief. The arrangement of the eight-gauge-within-a-square networks was chosen so that the mean of their values would provide the "best" estimate of the mean rainfall over the square: this resulted in a diamond-within-a-square configuration.

Data archiving and quality control procedures have been developed and the resulting HYREX database at IH is available to the whole HYREX community through remote FTP transfer. Quality control procedures

have involved preparing simple monthly tabulations of rainfall totals for each gauge along with cumulative hyetographs. These have served to highlight the time of inception of new gauges, the malfunctioning of others and the broad range of rainfall variability experienced. Monthly rainfall fields have been derived by multiquadric interpolation and used to identify gauge malfunction and to expose the influence of orography on rainfall amounts over the Brue catchment. Ratios of gauge to coincident radar estimates of rainfall have been calculated and averaged over a month, using both 2 and 5 km grid square radar data from Wardon Hill and Cobbacombe. This has exposed that both radars are underestimating rainfall, with Cobbacombe being worse.

Automatic Weather and Soil Moisture Stations have been installed in the eight-gauge low relief square within the same fenced compound. Data from these stations support a water balance calculation within the network design study. The drop size distributions obtained from an optical disdrometer deployed nearby during selected 'intense observing periods' are used to estimate radar reflectivity and rain rate, and to investigate how the relationship between them departs from the standard Marshall-Palmer form normally used for radar rainfall estimation.

Current work is focusing on issues concerning rainfall measurement accuracy using the unique HYREX dataset. Empirical measures of accuracy, not based on spatial correlation functions, are being used to explore the dependence of rainfall estimation accuracy on rainfall magnitude. A simple approach being pursued is to use the average of the values from the eight gauges in a 2 km square as the "true rainfall". Departures from this at each gauge are then used to compute the standard error associated with a single gauge estimate. Plotting the standard error against the true rainfall for each 15-minute wet period yields an empirical relationship between gauge accuracy and rainfall magnitude. This can also be done for radar data, using the same true rainfall, and the accuracy relationship compared (see left).

Storm model radar rainfall forecasting

Unfortunately, the current generation of mesoscale models represent storm dynamics on too coarse a grid to meet the hydrologists' needs — 16 km in the case of the UK Met. Office Mesoscale Model — with highly parameterised representations, for example, of convective cloud systems. Disaggregation of mesoscale model rainfall to smaller scales provides one possible way forward. An interesting alternative is to pursue the physics-based approach at a smaller scale and a higher level of process representation. An extreme approach would be to employ one of the number of detailed cloud models currently being developed to support studies of precipitation formation.

One form of simple cloud model, based on developments of Georgakakos and workers at the University of Iowa, is being pursued in collaboration with the Joint Centre for Mesoscale Meteorology, University of Reading. Clearly, the use of a simple water balance of the atmospheric column, with frequent state updating, in conjunction with radar inference of its advective movement, offers an attractive way forward for forecasting the development of storm systems. Since the model is essentially a simple dynamic water balance of the lower atmosphere it has much in common with the conceptual catchment water balance models familiar to hydrologists working in the land phase of the hydrological cycle. Using a rainfall model parameterisation commensurate with that of a catchment model clearly has much to commend it for the purposes of storm and flood forecasting. Depending on the resolution of the radar data, the model is capable of representing rainfall fields for 1, 2 or 5 km grids and for time intervals of from 5 to 15 minutes, for example, clearly meeting the hydrologist's requirement for forecasts at this fine resolution in space and time.

Preliminary results, when applied to southern England using data from the Wardon Hill weather radar in Dorset, show that whilst the model forecasts the development of frontal events with some success one hour ahead, it is less able to forecast the more rapid growth and decay of convective storms.

The general approach of using a simple dynamic rainfall model with frequent assimilation of real-time data from weather radar, satellite and surface weather stations has considerable appeal. However, some further research is still necessary on both model formulation and use of the new generation of Doppler weather radars but the potential improvements in flood forecasting and warning of rainfall forecasts even half-an-hour ahead during convective storms, at spatial and temporal scales of 2 km and 15 minutes, makes research progress in this area particularly worthwhile.

Contact: Bob Moore

Modelling global water scarcity

Rapid increase in population and in food production, combined with urbanisation and industrial development has led to the prospect of a crisis in both the quantity and quality of water supplies and the consequent risk of socio-economic disruption, especially in less-developed countries. Natural variations in climate also add further uncertainty to the future availability and distribution of water resources.

To help define the parts of the world that are currently suffering the worst problems of water scarcity and those areas which are likely to experience water scarcity in the future, we are co-operating with the British Geological Survey with funding by the Overseas Development Administration on improving methods of assessing the availability of water resources on a global scale and designing user-friendly software to display these results. The basic approach relies on the use of a 0.5° by 0.5° grid, which allows the spatial variability in both the availability of water and the demands for water to be represented. In contrast, most previous studies have examined country-wide aggregates of resources and demand, which can mask significant variations between different parts of the same country.

The approach that is being developed includes the following elements:

- A consistent methodology is applied in each grid cell, across all countries and regions. Several global datasets at this resolution are now available, providing some of the input data needed for the model, and allowing the possibility of extension to worldwide coverage.

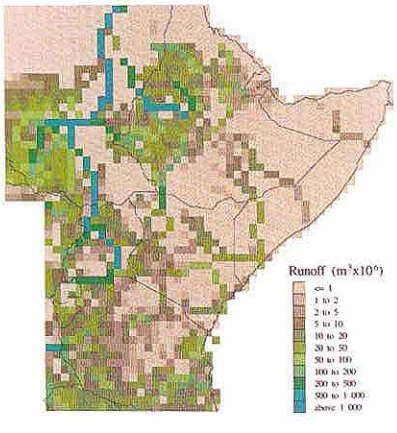
- The individual grid cells are linked to model the flow patterns of the natural drainage basins since the drainage basin is the logical unit for examining resources; it also allows problems of transfers between countries sharing the same basin to be considered.

- Within each grid cell the surface water resources are assessed using a rainfall-runoff model. Both the locally-generated runoff and that arriving from upstream are considered. Seasonal and year-to-year variability in the surface water flows are taken into account to assess the amount of water which is actually available for use at different levels of reliability (see below). The effects of lakes, reservoirs and wetlands and of water consumed and return flows are included in assessing the surface water availability.

- Groundwater availability in each grid cell, taking into account water quality, is also assessed and added to the surface water availability to provide an estimate of the total water availability for the cell.

- Water demands, including those for human and livestock consumption, industry and irrigation, are assessed and compared to the water availability for the cell to derive an index of water abundance or scarcity for each grid cell.

- The model allows the examination of a range of scenarios of change, including factors such as population growth, urbanisation, economic development and climate change to estimate the magnitude of possible future water resources problems.

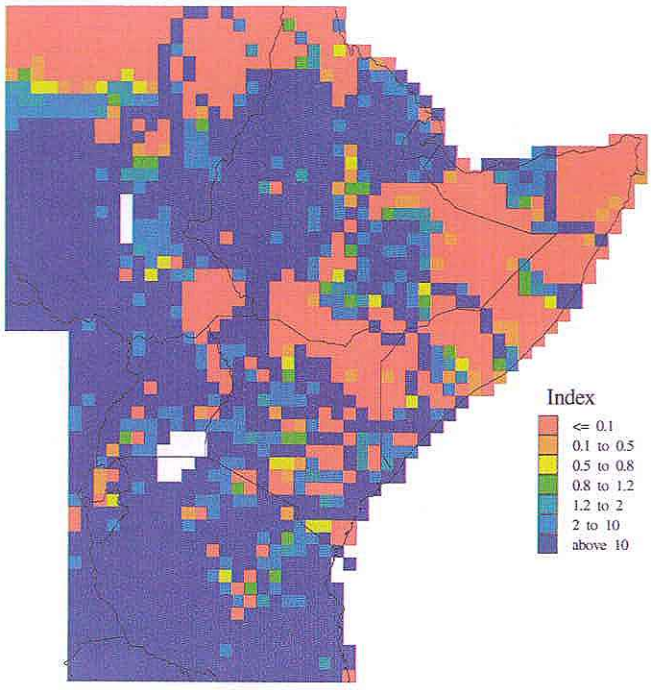


90% reliable monthly runoff for eastern Africa

- The results can be presented using a GIS and user-friendly software, providing a visual index of water availability or scarcity in different regions, and a flexible range of options for examining the results in different ways.

So far, a preliminary methodology has been developed and tested on a part of eastern Africa. The results for surface water only are shown on the right: the index used compares the availability of water with the current demands. Future studies will concentrate on improving the modelling, combining the surface and groundwater assessments into a single index and extending the coverage of the model.

Contact: Jeremy Meigh



Index of surface water availability for eastern Africa. The index is the ratio of the available surface water supplies to the demand.

Hydro-ecological modelling: a basis for river management

Hydro-ecological modelling work at IH focuses on methods and tools to assist the ecologically sound management of rivers. A major part of this work is the development of the Physical Habitat Simulation (PHABSIM) model for UK application. PHABSIM is a hydro-ecological computer model designed to assess impacts caused by changing flow regimes, or channel geometry, upon the available habitat for selected species.

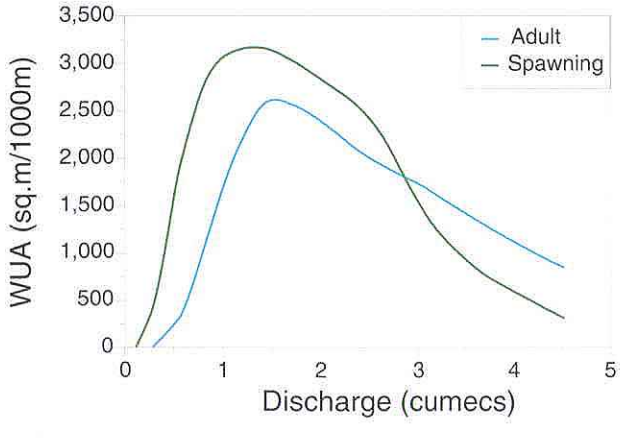
Originally produced by the US Fish & Wildlife Service, PHABSIM simulates the relationship between streamflow and the available physical habitat (as defined by water depth and velocity, substrate and available cover). It contains a number of hydraulic models which simulate values of depth and velocity under selected flow conditions. These models are calibrated using flow data collected "on site" at one or more calibration discharges (see below). Observations of substrate and cover are also recorded and are assumed

Collecting PHABSIM calibration data on the River Wey study site

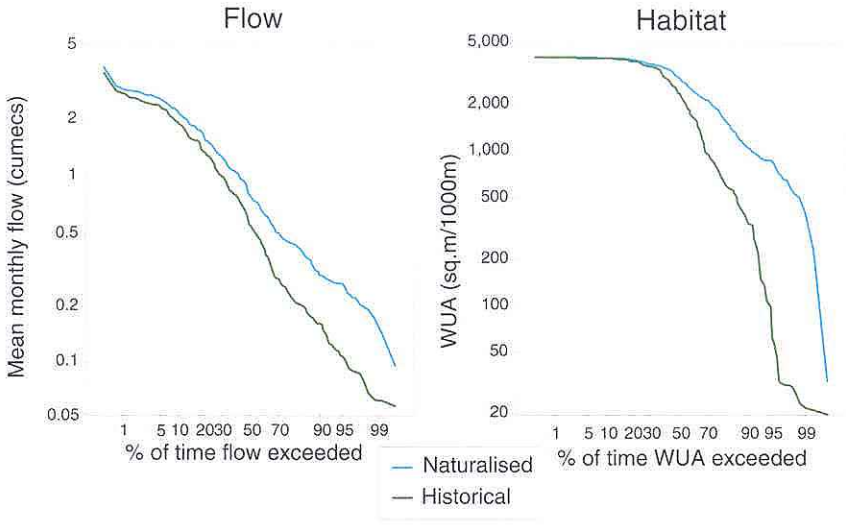
to be independent of discharge. Once calibrated to a study site, the model can simulate values of microhabitat variables over the full range of discharges within the river reach in question.

The simulated values of the microhabitat variables modelled within PHABSIM are combined with data which describe the relative suitability of those variables for the selected target species life stages. These data are termed "habitat suitability indices" and may be derived from expert opinion, existing literature or by field sampling. For application in the UK, a range of these indices has been produced in collaboration with the Institute of Freshwater Ecology and by the National Rivers Authority. The habitat models within PHABSIM combine these two sets of information to produce results showing the available habitat within the study reach, expressed as weighted usable area (WUA) against discharge. An example of this type of output is given below, showing changes in WUA with flow for the adult and spawning life stages of dace at the Mill Stream study site.

The first applications of PHABSIM in the UK took place on the rivers Blithe and Gwash under a Department of the Environment commission which began in 1988. Subsequently, the model has been the focus of an ongoing National Rivers Authority R&D project on ecologically acceptable flows. Under Phase I, the model was applied to ten rivers throughout England and Wales. These were chosen to represent a wide range of aquatic systems and to examine a range of common problems, including sites affected by reservoir compensation flows and intensively regulated river systems. Further, NRA-commissioned operational studies on the rivers Allen, Piddle, Bray and Barle demonstrated the model's usefulness in examining UK water resource issues. Phase II includes extrapolation of model results from the study reach to longer lengths, or sectors, of river. The dissemination of the knowledge and skills gained during this work has been a high priority and a PHABSIM training course was held for NRA staff.



Example WUA vs *discharge output for the adult and spawning life stages of dace (Mill Stream study site)*



Example flow and habitat duration curves (River Allen downstream study site)

Other innovative research using PHABSIM includes joint research with the Institute of Freshwater Ecology on faunal and floral response to reduced flows and habitat loss in rivers, a study of how populations of aquatic species respond to changes in river flow regime. This study centred on a 200 m reach of the Mill Stream at the IFE River Laboratory, Wareham, where a programme of intensive field data collection has taken place with the installation of an automatic water level logging system to record hourly water levels at each of 15 study transects within the reach. Research funded by MAFF has examined habitat improvement/ restoration procedures which are being applied with increasing frequency at UK river sites.

Continued refinement to the PHASBIM software in response to the needs of potential UK users has included some rationalisation to simplify the modelling procedure and the incorporation of new graphics facilities to aid the interpretation of model outputs. A further advance is the incorporation of software to allow temporal analysis of available habitat. This is achieved by combining the WUA/ discharge functions, produced using

the PHABSIM habitat models with river flow data. The flow data used may be obtained from river gauging stations or by using hydrological models to simulate data with or without artificial influences. This combination produces a time series of available habitat under existing and simulated flow conditions. An example of this is shown left where the habitat time series have been converted to "habitat duration curves". This facilitates the interpretation of ecological data using techniques familiar to water resource planners.

Contact: Craig Elliott

Rainfall frequency analysis of drought severity

Is a hosepipe ban the harbinger of a good summer or a sign of resource mismanagement? From a global perspective, water scarcity in the UK is not a problem. However, with supply companies no longer in conventional public ownership, it is inevitable that consumers are concerned to receive an appropriate level of service at all times. So how does the resource manager argue and support the contention that the need to restrict water use has arisen naturally?

Typically, quantitative assessments of drought severity are kept simple. Rainfall is a convenient common denominator: the phenomenon is well known to the public, and relatively long-term records are usually available. If the on-going drought is unprecedented in terms of rainfall, it should be easy to convince the regulator that restrictions on water usage are necessary.

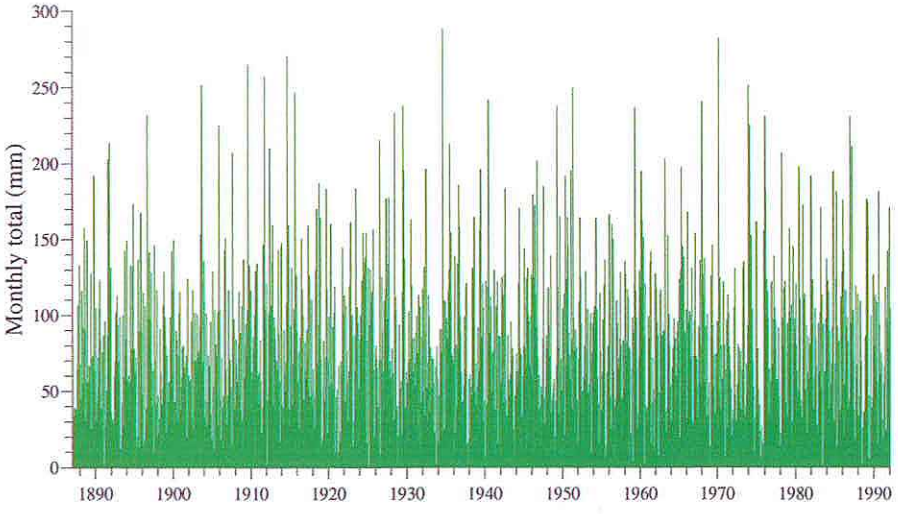
A typical supporting statement is that the gauge at Great Dryby has never previously recorded so little rain in a four-month period beginning April, since records began in the year dot. If the historical comparison is obscure (e.g. second smallest 3-month rainfall since computerised records began), quoting the drought rarity as a return period in years may be slicker. While historical comparisons and statistical assessments are fine when applied to a direct measure of resource, such as river flow or groundwater level, those based on rainfall totals should not pass unchallenged. At best, they are misleading.

The underlying weakness is that a particular water resource system is not uniquely sensitive to dry spells of a specific duration, or to droughts beginning in a given month. Thus it is incorrect to interpret an assessment of rainfall rarity made for a *particular* combination of duration and start-month as indicative of the severity of the water resource problem being faced. In practice, such estimates grossly over-estimate the drought rarity. Some users recognize this and, by a rule of thumb, divide the assessed return period by ten. Clearly a more scientific approach is required.

There are two features to note. While some durations and start-months are likely to cause difficulty more often than others, a given water resource system will be sensitive to rainfall droughts of a range of durations and start-months. Further, there is considerable temporal dependence between droughts of differing duration and start-month. For example, an extreme 18-month drought will inevitably include an extreme 17-month drought.

The assessment of drought severity

from rainfall data is a theme of the *Analysis of Dependent Time-series (ADEPT)* project, funded by NERC. Initial work is investigating the dependence found in drought rainfalls of different duration. The figure on the right shows the monthly rainfall series for a long-term composite record for Chilgrove in West Sussex, spanning the century beginning January 1890. Additional years at the start and end of the record allow centennial droughts to be defined for durations up to 48 months, free from end effects.



Long-term monthly rainfall series typical of Chilgrove in West Sussex

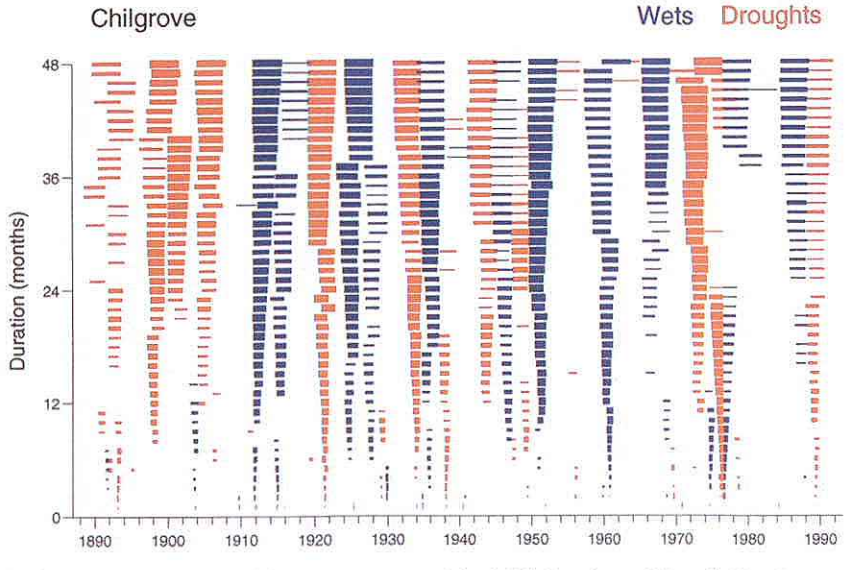
The red rectangles in the figure below depict the ten worst droughts of each duration, defined as the smallest non-overlapping accumulations. The lateral extent of the rectangle indicates the timing of the drought. The rectangle height denotes the historical rank, the most extreme drought being given most prominence. For example, the red rectangles along the top of the figure indicate that the two worst 48-month droughts occurred in the mid 1970s and the late 1890s. The blue rectangles denote the ten wettest periods of each duration, referred to here as "wets".

Three findings spring from this relatively simple display. First, given the red/blue overlaps, it is impractical — even with a century of record — to define as many as ten droughts (or wets) for durations greater than 24 months. Thus, severity assessments inevitably become more problematic as the duration of interest increases.

Second, there is strong temporal dependence in droughts (and wets) of different durations. While in many ways an obvious statement, its implication for wrecking inferences of water resource stress from fixed-duration assessments of rainfall severity is poorly appreciated.

Finally, the figure below shows that some notable dry and wet periods have beset this part of southern Britain. For example, it is seen that the 1975/76 drought formed part of a longer dry era beginning in the early 1970s, and was unusual in its late intensification. Nor within the gauged record was there precedent for a severe drought to be promptly succeeded by a notable wet, as occurred in 1976.

If due account can be taken of temporal dependence, the abuse of rainfall assessments of drought severity should be arrested. In seeking to associate water resource stress with low rainfall, one should of course pick the rainfall record that is most relevant to the water resource. If the manager insists on quoting Great Dryby — in preference to rainfall depths at Centroidington or Cataversham — some bias will remain!



A schematic representation of the ten worst centennial rainfall droughts and "wets", West Sussex

Contact: Duncan Reed

1994/95 highlights

Development of improved methods of snowmelt forecasting (for NRA). Review of historical snow data, enhancement of instrumentation for study basins in four field areas and exploration of lumped and distributed snowmelt model formulations for use in operational flood forecasting.

Storms, floods and radar hydrology (for CEC Environment Programme). Investigating the use of weather radar for measuring and forecasting storms and floods.

Design of radar/raingauge networks for hydrological use (NERC special topic). Using a network of over 50 recording raingauges in the Brue catchment, Somerset, along with three scanning radars, to investigate the accuracy of different sensors to measure rainfall, the natural variability of rainfall and the sensitivity of catchment runoff and models to rainfall uncertainty and variability.

Short-period rainfall and flow forecasting incorporating weather radar data (NERC Special Topic). Collaboration with Reading University in the development of a physical-conceptual rainfall forecasting model incorporating weather radar, weather station and Meteosat data, in conjunction with a rainfall-runoff model for real-time flood forecasting.

Real-time forecasting of river flows (for MAFF). Strategic research on real-time flow forecasting in England and Wales, including a review of research and development needs in this area.

London weather radar calibration for the Thames Basin (for NRA Thames Region). A project to extend the London Weather Radar Calibration Procedure, originally developed for London and the Lee Valley, to the entire Thames Basin using data from some 70 raingauges.

River Soar flood warning system (for NRA Severn-Trent Region). Investigation into the flood warning methodology for the River Soar extending from hydrometric network design, through modelling of a river experiencing flood plain flows and backwater influences from navigation and flood gate controls, to flood forecasting system design issues.

River Flow Forecasting System (for NRA Northumbria, Yorkshire and Thames). Continued maintenance and support of the RFFS for the rivers of Yorkshire. Supply of the RFFS Information Control Algorithm and rainfall-runoff model algorithms and configuration to support 30 forecast points in the Thames Basin.

Rainfall frequency estimation in the UK A new method of deriving rainfall growth curves has been developed in a pilot study in the East Midlands. The growth curves can be focused on any location and applicable to a wide range of durations and return periods. The curves are used with maps of an index variable produced by the technique of kriging to provide rainfall frequency estimates at any point.

Allowance for discretization in hydrological and environmental risk estimation. The effect of

data discretization upon the estimation of environmental extremes has been examined, with emphasis on rainfall time series. Recommendations have been published for making the necessary corrections to estimates of mean period maxima.

Confluence flood joint probability Methods are being investigated which estimate flood probabilities at the confluence of two rivers. The dependence between flooding in each of the tributaries is to be taken into account in a simple but consistent way.

Flood Estimation Handbook (for MAFF, NRA, DANI). Holdings of flood peak data are being updated in co-operation with gauging authorities. Indices representing the seasonality of extreme rainfalls have been added to those developed previously for peaks-over-threshold flood data. The indices form the input to a cluster analysis to propose catchment groupings for regional flood frequency analysis. Research progress is reported to a Flood Estimation Handbook Advisory Group, chaired by MAFF, and including representatives from funding organisations, consulting engineers, the Met Office and academia.

Assessment/design of habitat improvement/restoration procedures for river flood defence schemes (for MAFF). Application of the IFIM to a case study on the River Wey.

Faunal and floral response to reduced flows and habitat loss. Collaboration with IFE, Wareham, examining and modelling changes in biota of a river under reduced flow conditions.

Southern Africa FRIEND A large hydrological database has been established in association with the 11 countries of the SADC. Low flow and flood frequency research is undertaken, using over 660 daily time series and GIS techniques.

European atlas of small-scale hydropower resources (for EC ALTENER programme). Completion of software for assessment of hydropower potential at ungauged sites in Spain, Italy and UK.

European water archive data centre in St Petersburg The establishment of a regional data centre for the European territories of the former Soviet Union at the State Hydrological Institute in St Petersburg.

Tanzania urban sector strengthening (for Howard Humphries & Gibb Eastern Africa) Ltd) has centred on the water supply to Morogoro, about 200 km inland of Dar-Es-Salam, and Tanga, on the coast to the north near the Kenyan border. Assessment of reliable yield of an existing reservoir was required for each town, with assessment of the potential yield of nearby river and spring sources also undertaken for Morogoro.

Hydrological review of the Kafue River, Zambia (for Booker Tate Ltd). The primary objective was to ascertain whether there was sufficient water downstream of the Itezhi-itezhi reservoir to service the Zambian sugar industry in the future. The impact of proposed future irrigation abstraction on energy production at the Kafue Gorge hydropower plant downstream was assessed, with both existing and possible future operating rules.

Hydrological and hydraulic investigations of Hung Shui channel, Hong Kong Investigation of causes of two recent major floods, Nov 1993 and July 1994, plus recommendations for short and long term remedial measures.

Sandpool Farm flood study (for Hill Aggregates Ltd) Assessing the effect of proposed landfill on floodplain storage in the Flagham Brook catchment, upper Thames Basin.

Water resources development project, The Philippines (for World Bank) Runoff available for irrigation and the flood peaks were assessed for 38 major irrigation schemes throughout the Philippines, with a manual and training provided for local staff.

Extension to World Flood Study (for ODA) Methods of flood estimation, using the regional approach, were derived for 17 countries or larger regions in the developing world. The methods are immediately useful for rapid flood estimates, especially for sites with no observed flow data. A user-friendly software package for regional flood frequency analysis was also produced.

Digital data, software trials and the communications era are transforming the scale and pace of this Institute's research. It is pleasing to report that the first year of an Information Hydrology Division created to focus and capitalise on IT opportunities for better research and technology transfer has been both effective and harmonious. Already the strength of being part of a wider Centre for Ecology and Hydrology is being felt. Thus the Division now provides software support for ITE's Countryside Information System whilst GIS skills are being shared with IFE.

Information Hydrology

The mission of the division is clear-cut:

- to collate, quality control and publish time series and spatial datasets that describe any part of the hydrological cycle over a region;
- to reveal the coherent structures within environmental datasets relevant to the water industry;
- to program to commercial standards the scientific findings of the Institute as well as publishing them through every relevant outlet in printed and electronic form;
- to use metadata cataloguing and wide area networks to collect and distribute the facts on which the subject flourishes;
- to bring advances in information technology into the hands of water scientists in NERC, the UK water industry and academia.

The articles that follow amply demonstrate the new digital data and communications era that is transforming the scale and pace of the Institute's research. In particular, the role of Data Centres and Data Plans is giving a new coherence to community research programmes — and this can be expected to lead to longer term benefits from the expenditure incurred; the LOIS activities described overleaf are an excellent example of linking data past and present within a powerful new information system.

THE RIVERS DATA CENTRE

A perspective on the Data Centre managing the integration of time series and spatial data for the rivers component of the Land Ocean Interaction Study (LOIS)

Isabella Tindall

Coastal areas provide both a rich diversity of environments and habitats and many opportunities for industrial, commercial and recreational activities. Inevitably the increasing exploitation of coastal zones produces conflicting pressures which, if not carefully managed, can result in the degradation of an especially sensitive environment. This danger provided the stimulus for the Land Ocean Interface Study (LOIS) which focuses on the links between the terrestrial and marine environments (see also page 35). At present, understanding of the processes at work is incomplete and the purpose of LOIS is to extend our knowledge of the movement of fluxes between the different components of the environment, particularly the land, air and ocean phases. This knowledge will then be built into predictive models to help gauge the impact of land use, climate and other changes on the coastal areas. The results from the most appropriate scenarios will then be available to develop a legislative and regulatory framework to encourage sustainable management of our coasts.

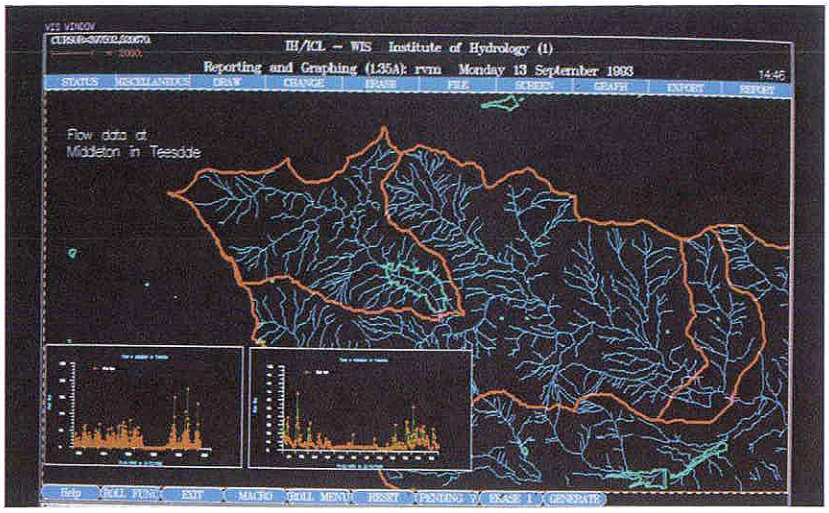
Environmental problems increasingly span many subject areas and often require an integrated multi-disciplinary scientific approach. Correspondingly, LOIS is an inter-Directorate NERC Community Research project with a £30 million five-year budget in which many NERC Institutes and UK Higher Education Institutions are participating. Information is vital to such a study: the effective collation and manipulation of data from a wide variety of sources and subject areas is one of the keys to attaining the programme's scientific objectives. A novel aspect of LOIS is the creation of five thematic Data Centres responsible for the acquisition and distribution of data from and to the researchers. The Rivers Data Centre is located at IH and is using its Water Information System (WIS) to integrate, manage and analyse highly diverse datasets of both spatial and time series origin within a single unified 4-D database.

The River Swale upstream of the confluence with the Ouse

Within the broad objective of predicting the likely impact upon, and response of, the UK coastal zone to natural and man-made environmental changes in the next 50-100 years, four major themes for LOIS are evident:

- To characterise and measure the fluxes of materials and energy into the coastal zone from the rivers, atmosphere and ocean.
- To identify and quantify the processes that govern such fluxes to and from the coastal zone.
- To provide a long term perspective of flux variability across a range of time scales — the last 200 years to the Holocene period as a whole.
- To develop integrated land-ocean models of environmental change in the coastal zone.

The principal study area extends from Berwick-on-Tweed in the north to Great Yarmouth in the south. It embraces a rich diversity of land use and river types, from the fast flowing streams draining the



WIS output showing integration of time series datasets

northern Pennines, through the industrial rivers of south Yorkshire, to the sluggish and nutrient-rich lowland rivers of East Anglia.

LOIS consists of five integrated component studies: the River, Atmosphere, Coastal Study (RACS), the Shelf Edge Study (SES), the North Sea Modelling Study (NORMS), the Land Ocean Evolution Perspective Study (LOEPS), and the DATA component. The latter is a recognition of the pivotal role played by data management in the LOIS programme.

Each of the five Data Centres has responsibility for specific data categories and the duty to:

- Acquire major datasets from within and without NERC and make them available to the LOIS community;
- Provide data management services for LOIS data including quality control and archiving;
- Provide long term security for all the LOIS data.

The IH Rivers Data Centre

The Rivers Data Centre is responsible for all catchment-based data — both time series and spatial — of which the main suppliers are the National Rivers Authority (NRA) and the LOIS York Laboratory. The NRA collect, analyse and manage time series data for the great majority of the river catchments and have agreed to supply those datasets of particular interest to the LOIS project. These include: river water quality data, river water quantity data, consent to discharge data, abstraction licence data and biological data. Spatial datasets being used by LOIS researchers include: the IH digital river network (at 1:50000 scale), the IH 1 km Digital Terrain Model (IHDTM), Flood Studies Report maps, the Institute of Terrestrial Ecology's 25 m Land Cover data, the Hydrology of Soil Types (HOST) 1 km grid, Bartholomew's urban and road/rail network data and the Ministry of Agriculture Fisheries and Food's Small Area Agricultural Statistics data.

Increasing awareness of the commercial value of data has created a new and unwelcome task for the Data Centres, that of negotiating terms and conditions for the use of externally supplied data. The requirement to protect copyright and create income undoubtedly slows the uptake of information contained in datasets.

To create the required integration of time series and spatial observations within a single database, the Data Centre is faced with a challenging task of matching data types from different sources. There has been no standard encoding system for similar data types within the different regions of the NRA, or between water quality data from freshwater and marine sources. Consequently, estuarine modellers requiring, say heavy metal data, from both the Rivers and Marine Data Centres need to be assured that they are comparing data of similar analytical origin or quality. Therefore, one of the Rivers Data Centre's first tasks was to harmonise the data from the individual NRA regions with existing chemical determinand dictionaries: such reference compilations play an indispensable role in establishing standardised data transfer and exchange procedures. Once the data were harmonised in a dictionary, cross-reference tables were designed that translated the data from the codes in which they were supplied to those in which they are now stored in the database. With the publication of the LOIS chemical determinand dictionary scheduled for the autumn of 1995, the next major task of harmonising data from freshwater and marine sources should be much easier.

The Rivers Data Centre is using WIS, the Environmental Information System designed and developed at the Institute over the past five years in collaboration with ICL. WIS stores and manages all the catchment associated data required by the modellers working on the RACS Rivers component of LOIS. WIS has a geographical user interface and allows the user to record the history of any object, or feature, as it moves through space and time. Events

occurring at features can be described in terms of attributes which may be spatial or time series in nature. Uniquely, WIS does not distinguish between spatial and time series attributes, but stores them in a single unified database which allows the user to link and analyse spatial and time series datasets.

WIS has been installed on new hardware with over 10 Gb of file storage space and 10 Gb of database space. The LOIS data volumes are expected to rise from an initial 10 Gb to approaching 20 Gb as more data are both derived by the project and become available from other sources. Within the last year the Data Centre has been busy confirming and updating its Determinand Dictionaries and translation tables for the loading of time series data and many software programs have had to be written to convert externally supplied data. The Yorkshire water quality data for several thousand river monitoring sites have been processed and the attribute data for over 300 determinand types have been loaded into the WIS database. Bringing together the water quality data and corresponding river flows stored on the National Water Archive allows the complex interactions between flow and determinand concentrations to be examined and mass flows into the North Sea to be computed. The next data types to be processed will be the Yorkshire consent-to-discharge data and the Severn-Trent NRA water quality data.

To support the major LOIS objective of developing integrated simulation models that will allow better predictions over time, the Data Centres are currently integrating and harmonising the datasets under their aegis. The next challenge is to standardise the datasets across the different component Data Centres. This represents a substantial task but the aim, by the end of the LOIS project in 1998, is to create a truly integrated dataset which should be available on CD-ROM for public use and further scientific investigation.

A flood risk map for England and Wales

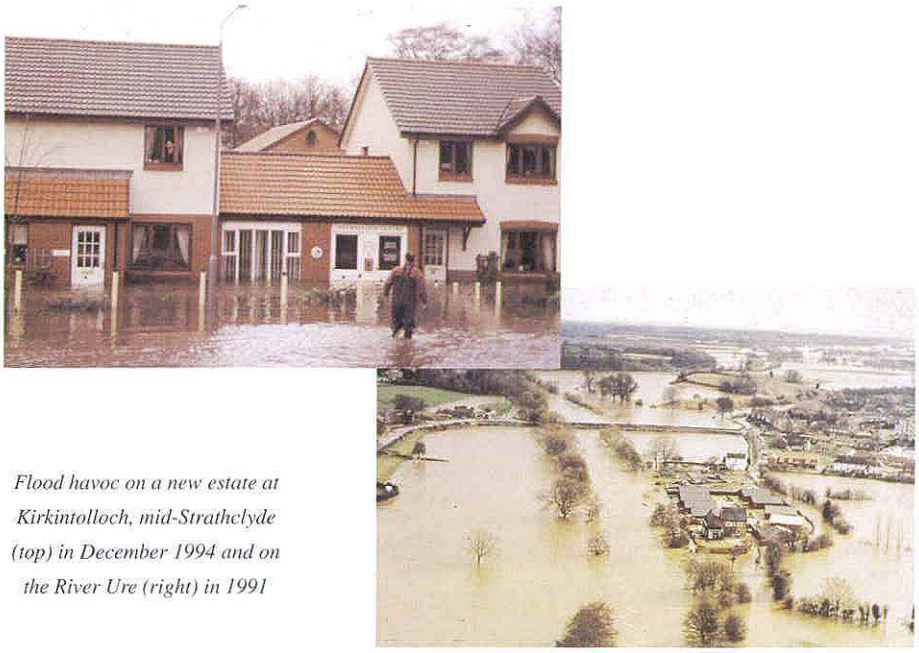
Flood warning procedures and alleviation measures have mitigated the threat of flooding in many UK catchments. However, floodplains continue to offer attractive development opportunities and expose a substantial proportion of the population, and much commercial activity, to the risk of inundation. Damage in excess of £100 million resulting from the mid-Strathclyde flooding in December 1994 provided a sharp reminder of the need for more effective catchment management, planning controls and insurance arrangements. Direct experience of extreme flood events is necessarily rare but the joint exploitation of major spatial datasets and newly developed modelling techniques now allow the likely impact of exceptional flooding to be explored at the national scale.

The Institute was commissioned by MAFF to estimate the total area of England and Wales that, in the absence of any flood defences, would be inundated by fluvial floods of the 100-year return period level. The project also involves identifying the built-up area that would be at risk. There has been no previous nationwide estimate of these quantities at this level of detail.

Progress in evaluating the spatial extent of severe flooding has been made possible by several recent

developments at IH, namely:

- the completion, for England and Wales, of the Institute of Hydrology Digital Terrain Model (IHDTM);
- the development of methods of estimating flood depths directly from catchment characteristics;
- the completion, for England and Wales, of the IH digital river centre-line network based on Ordnance Survey 1:50,000 maps;
- the establishment of digital spatial datasets that allow catchment characteristics to be computed automatically to any point on the river network;
- the production of a national digital dataset of built-up areas (based on the Institute of Terrestrial Ecology's Land Cover Map of Great Britain and OS 1:250,000 digital settlement data); and
- the development of techniques and software for exploiting and displaying digital spatial data.



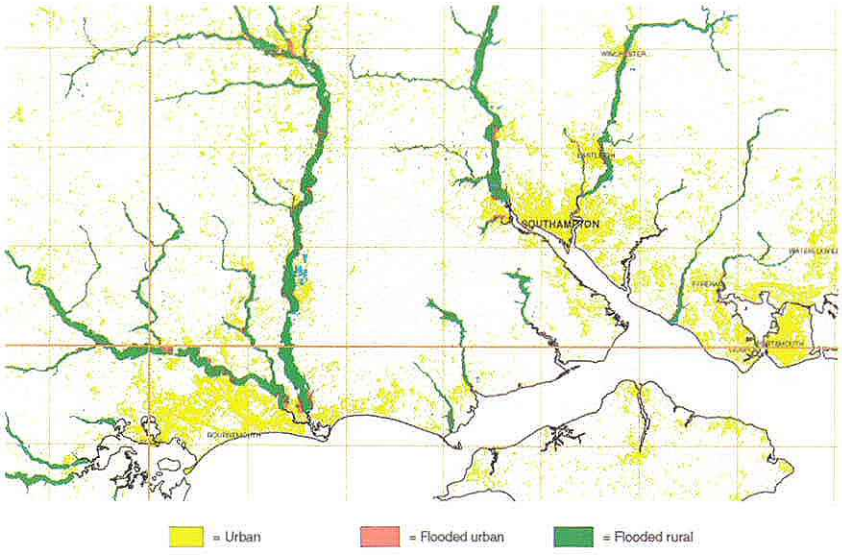
Flood havoc on a new estate at Kirkintolloch, mid-Strathclyde (top) in December 1994 and on the River Ure (right) in 1991

The analysis has been conducted on a 50 m square grid, which is the horizontal resolution of IHDTM. Also represented on the grid is the 1:50,000 river network, and the 100-year flood depth has been computed for every point where the catchment area exceeds 10 km^2. Equations relate mean annual maximum water depth to catchment characteristics (area, rainfall and soil) and growth curves which enable depths of return periods of up to 200 years to be broadly assessed.

Estimates of the depth of the 100-year flood at the river bank have been obtained by taking the difference between the river depths of the 100-year event and the mean annual maximum (assuming that, typically, the latter represents a depth just greater than bankfull). As local channel conditions are not taken into account there is a significant degree of uncertainty associated with the results at any particular location; however, it is believed that this approach provides a valid way of quantifying relative risk at the regional and national level.

The areal extent of inundation has been determined by taking each flooded river point in turn and using the IHDTM to identify contiguous areas of higher land that are lower than or equal to the elevation of the flood surface. This approach obviates the need to model the flow of water down the floodplain and, as it is not catchment-based, allows a flood from the major river in a valley to spread across any minor tributaries or braids.

The resulting maps of flood extent have been compared with existing maps of flood risk (mostly Section 24(5) maps produced by the former Water Authorities) at over 30



A portion of one of the flood risk maps from the draft report

locations throughout England and Wales and a good correspondence has been recorded in many cases.

Initial results — which exclude the areas covered by the Anglian and former Yorkshire regions of the National Rivers Authority — have been derived using a provisional version of the built-up areas dataset. These suggest that 4200 km^2 of land would be at risk, of which 460 km^2 is built-up. Improvements to the built-up areas dataset are expected to lead to a small reduction in the latter figure.

Contacts: David Morris or Robert Flavin

Is the past still the key to the future ?

Hydrometric data are the foundation upon which hydrological science and water management are built. A detailed understanding of the variability of rainfall, runoff and aquifer recharge rates is a prerequisite for effective planning strategies and operational procedures to combat the effects of too little or too much rainfall. Fortunately in this context, most lengthy hydrometric series for the United Kingdom — while displaying notable perturbations — are characterised by little or no overall trend. However, the remarkable climatic conditions experienced over the last decade have raised important questions regarding the representativeness and resilience of index hydrological statistics, the bulk of which are based on data collected over the last 30 years.

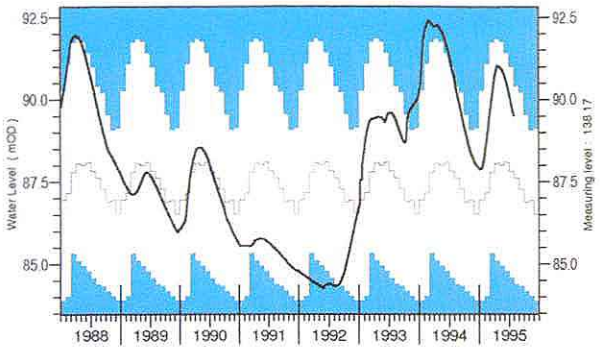
The possibility that hitherto rare climatic conditions may recur more frequently in the future underlines the importance of documenting and examining the range of impacts associated with the recent remarkable weather patterns. This need provided a primary justification for the establishment of a joint Institute of Hydrology/British Geological Survey national hydrological monitoring programme on behalf of the Department of the Environment and the National Rivers Authority. It was instigated early in 1989 as substantial rainfall deficiencies extended across much of the UK. Tthe drought proved to be exceptionally protracted and widespread, triggering fundamental reviews of water resource management in many parts of Europe.

By the summer of 1992 the water resources outlook for most of the UK was very fragile. Thereafter, a sequence of vigorous Atlantic frontal systems heralded a transformation in hydrological conditions that is without modern parallel. For England and Wales the driest 28-month sequence since the 1850s was succeeded by the second wettest 32-month sequence this century. The latter culminated in the exceptionally damaging floodplain inundation that afflicted western and northern Europe in the late-winter of 1994/95. Whilst superficially less

evident, the transformation was particularly dramatic in groundwater terms: in mid-1992 overall groundwater resources were estimated to be at their lowest this century but the subsequent steep water-table recoveries produced winter peaks in 1994 and 1995 that were close to all-time maxima.

Notably high annual precipitation totals have been a feature of western and Highland Scotland for more than a decade. Six of the wettest winter half-years in the 135-year Scottish rainfall series have occurred since 1983, contributing to a marked exaggeration in the normal north-west to south-east rainfall gradient across the UK. This is exemplified by the relation between rainfall for Fort William and Kew (London): the running average of the ratio of annual totals now exceeds the historical mean by a considerable margin (see below). The exceptional accumulated precipitation totals for Scotland over recent years have been associated with a cluster of major flood events which, for rivers draining the Highlands especially, have increased the expected frequency of damaging floods and prompted the introduction of restrictions on further floodplain development in some areas.

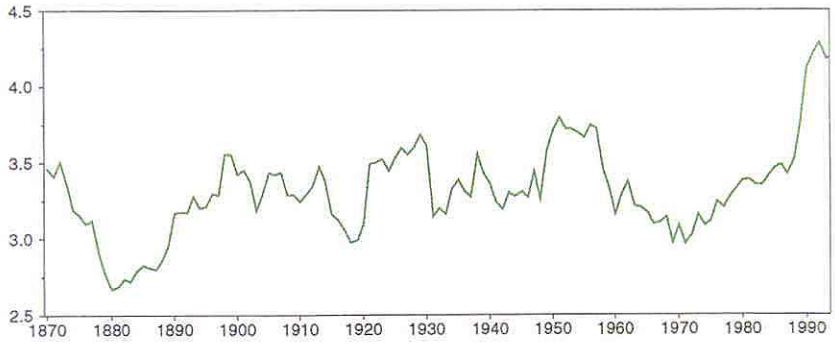
In hydrological terms, the effect of the recent unusual rainfall patterns has been heavily influenced by evaporation rates that have been equally exceptional. The recent tendency for climate zones to migrate northwards is reflected in the Central England Temperature Series which begins in 1659; the post-1987 average is appreciably higher than any other seven-year sequence and has contributed to potential evaporation rates typically 15% above average. The associated increase in soil moisture deficits has mitigated the risk of flooding over the summer half-year but narrowed the window of opportunity for winter recharge, especially to lowland aquifers.



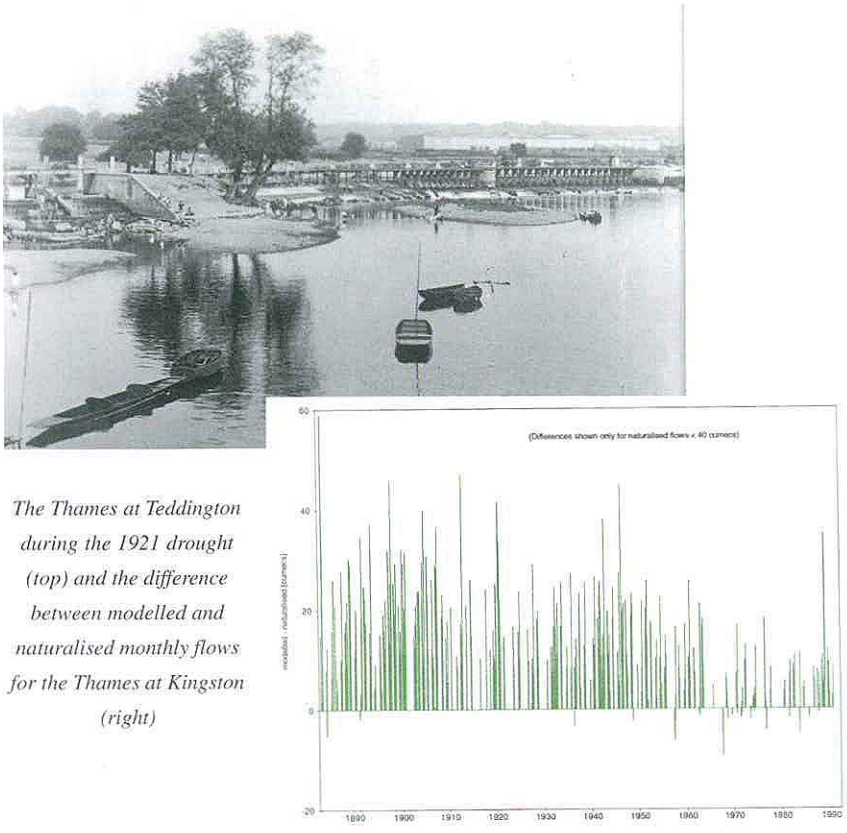
1988-95 groundwater level hydrograph for the Holt

Given the inherent variability of the UK climate, any apparent short term trends need to be treated with caution. The relatively short length of most river flow series — for the UK the average is below 25 years — provides an inadequate context in which to appraise the recent runoff patterns and can exaggerate the significance of the recent volatility. By capitalising on the limited number of lengthy hydrometric series available, a fuller historical perspective may be obtained. Unfortunately, relatively few long flow records are formally archived and considerable curatorial skills and hydrometric expertise are necessary to locate appropriate historical datasets and prepare them for general exploitation.

The utility of long hydrometric records can be greatly increased by the application of quality assurance procedures. The relevance of such techniques has been well demonstrated in a recent study of flow data for the Thames, one of the most intensively studied hydrological datasets in the world. Substantial changes in land use, river engineering, land drainage and floodplain management imply that significant regime changes would be expected over the last 150 years. Application of the IHACRES rainfall-runoff methodology to the 1883-1951 monthly flow record for Teddington Weir clearly indicates that such changes are insufficient to mask a systematic underestimation of the historical low flows. It appears that the conventional corrections applied to account for weir leakage and lockage losses are quite inadequate, especially around



Ratio of annual total rainfall for Fort William to Kew 1861-1994 (10-year running mean)



The Thames at Teddington during the 1921 drought (top) and the difference between modelled and naturalised monthly flows for the Thames at Kingston (right)

the turn of the century. Once a realistic adjustment is made to compensate for the early underestimation of flows, the relative severity of modern droughts increases markedly: the 1976 low flows have no close parallel and accumulated runoff over the 1988-92 period becomes comparable with the lowest on record.

Contact: Terry Marsh

Entering the Internet and CD-ROM design era

The ability to marshall and manipulate information is an essential prerequisite of almost all scientific investigations and an indispensable stage in the decision-making process. IH is looking to exploit advances in information technology to ensure that analysts, be they researchers, managers or policy makers, have ready access to relevant datasets and the means to capitalise on them. To service the needs of a rapidly expanding user-community, and to help realise the potential benefits of electronic publishing, software distribution and data dissemination, IH has recently taken delivery of a CD-ROM writer and initiated information provision across the World Wide Web (WWW).

CD-ROM publication: the pebbles have started to roll!

Using current technology, a CD-ROM has the capacity to store, cheaply and reliably, approximately 660 MBytes of uncompressed data — sufficient to store the entire UK National River Flow Archive. Technological improvement is expected to produce an order of magnitude increase in storage capacity. CD-ROMs represent a great step forward in computer-based data delivery, as it is now easy to distribute enormous datasets, at modest cost, without the need for large numbers of floppy disks, or for large amounts of hard disk space to be permanently allocated to a particular data set. One key advantage of CD-ROM, apart from its large capacity and durability, is that data can be held off-line, and brought on-line straightforwardly when access is required.

Over the last few years the cost of ownership of a CD-ROM drive has fallen dramatically and usage is rapidly extending through the

scientific, business and academic communities; domestic usage is also burgeoning. The cost of manufacture of the CD-ROM media itself has fallen at the same time, and it is possible to produce a CD-ROM with relative ease; the hardware required now costs less than £5000. Following the trial development of a CD-ROM layout, featuring a previous Annual Report, the Institute plans to make early use of CD-ROM technology to disseminate its science and data. Initially information delivery will focus on three areas:

- The distribution of large datasets, such as those available in the National Water Archive. It is envisaged that the basic data would be supported by reference and descriptive material to increase its utility and guide the interpretation of analyses; work is well advanced on developing an on-line gauging station register, incorporating network maps to facilitate station selection.

- The publication of reports, papers and packages, a number of which could usefully exploit the exciting opportunities that exist for a 'multimedia' approach using sound and pictures to maximise the impact of the material. From the perspective of the target audience, the contrast with traditional publications will also be emphasised by the ability to rapidly search documents and the direct computer accessibility of accompanying data sets.

- The distribution of software. Although most IH software products only occupy a few floppy disks, the possibility of encrypting them and placing them all on a single CD-ROM is under investigation. This would result in greater convenience for both our internal software development and for the customer, who could purchase a special code to unlock a specific product on the CD.

Contact: Kevin Black

Exploring the World Wide Web

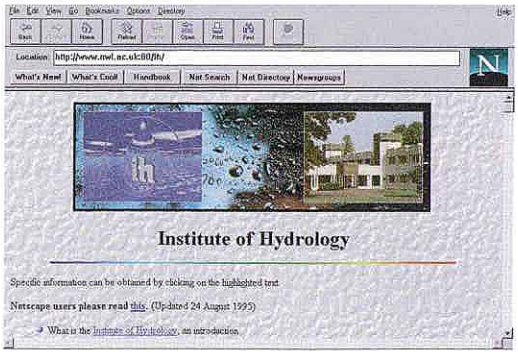
The World Wide Web is a facility that allows text, pictures and data to be accessed more easily across the global computer network, Internet. It seems destined to be a powerful dissemination tool whereby software allows users to search the network for information of interest. The World Wide Web's information base is expanding rapidly, can be updated immediately and is accessible to a world-wide audience. Information available can now be accessed using the address opposite. The ability to update material almost instantaneously allows IH software users to be kept informed about system enhancements and new developments; the WWW also enables potential users to acquaint themselves with facilities on offer.

We have recently extended the use of WWW facilities for the whole of the Institute, with information on research initiatives, publications and also the provision of selected datasets across the Internet. Details of the services available through the National Water Archive and summary material relating to the monthly national hydrological monitoring programme are already accessible. We are also researching hydrological WWW addresses and developing an on-line index allowing rapid access to hydrological information.

Contact: Robert Flavin or Charlotte Allen

The IH home page can be accessed using the Universal Resource Locator (URL) :
http://www.nwl.ac.uk ih

The Hydrology Software section's email address is:
softdev@ioh.ac.uk



The IH Home page, World Wide Web

The Library service

The Institute's Library is home to a comprehensive collection of books, reports and journals in the hydrosciences. It is also the focus for a variety of information services including retrospective bibliographic retrieval from on-line and CD-ROM sources. Updating and extending the information holdings is a continuing task and particular efforts are made to ensure there is good coverage of world hydrological literature.

The library's collection of CD-ROMs is increasing steadily and is proving a popular information source. Library users now have access to a range of bibliographic hydroscience databases from around the world. Recent acquisitions include: Delft Hydro (Netherlands), Aquaref (Canada), and Waterlit (South Africa). Selective dissemination of information is provided via ISI Current Contents on Diskette and the number of staff wishing to update themselves on recent scientific developments in particular fields has shown a healthy increase over the last year. As contact point for the BIDS ISI service the Library has also seen a brisk growth in new registrations of staff wishing to interrogate on-line Citation Indexes.

The Library is responsible for the sale and distribution of the majority of the Institute's publications. Overall sales are approaching three times those of five years ago and questions concerning the range and contents of IH publications form a significant proportion of the external queries handled each year. A third member of staff has proved extremely valuable, directly improving the service to Library users. Literature searches were at record levels in 1994 and a retrospective conversion of the old card-based catalogue records into the Library holdings database IHLIB is well advanced.

External requests to use the Library facilities — over 150 in 1994/95 — continue to rise. The strain this places on cramped study facilities, together with the limited amount of stock that can currently be held on the available shelf space, underlines the priority need for larger premises. More accommodation, especially reception and reading areas, is essential to maintain a responsive service to a broadening community of users and it is heartening that NERC's Business Plan allows for the necessary new building works beginning in FY 1996/97.

Contact: Sue Wharton

IAHS Press

IAHS Press, the publishing house of the International Association of Hydrological Sciences, has been based at IH for over 20 years. *Hydrological Sciences Journal*, the bimonthly scientific journal of IAHS, and the "Redbook" *Series of Proceedings and Reports* are the dominant publications. The output peaks in "odd" years when either a IAHS Scientific Assembly or a General Assembly of the International Union of Geodesy and Geophysics (IUGG), the parent body of IAHS, is held as the proceedings of up to six symposia held at such Assemblies are pre-published in the Redbook series. All the papers in IAHS Redbooks are reviewed, edited and presented in a consistent format and the books themselves sold internationally.

The Redbooks prepared in 1994 provide an excellent example of a well balanced publishing

programme for an inter-Assembly year. Two large pre-published proceedings and four post-published proceedings were produced:

Future Groundwater Resources at Risk (pre-published for the Helsinki FGR 94 Conference held in June); *Variability in Stream Erosion and Sediment Transport* (pre-published for the Symposium held at Canberra in December); *Hydrological, Chemical and Biological Processes of Transformation and Transport of Contaminants in Aquatic Environments* (post-published for the HYDROCHEMISTRY 1993 Symposium held at Rostov-on-Don); *Groundwater Quality Management* (post-published for the GQM 93 Conference held at Tallinn); *FRIEND: Flow Regimes from International Experimental and Network Data* (post-published for the FRIEND Conference held at Braunschweig) and; *Snow and Ice Covers: Interactions with the Atmosphere and Ecosystems* (post-published proceedings of two symposia held at Yokohama).

The major event for IAHS in 1995 was the XXI General Assembly of IUGG held at Boulder, Colorado, in July. Under the umbrella of a 'Geophysics and the Environment' theme a very wide range of symposia were scheduled including six organised by IAHS, all pre-published in the Redbook series. .

An encouraging development over the recent past has been an increase in the number of papers featured in the *Hydrological Sciences Journal* and a steady reduction in the time lag between receipt of the papers and their acceptance and final publication. The Journal is the oldest and most international of all the hydrology journals. In addition to providing a forum for original papers and significant developments in hydrology, it includes announcements on IAHS-organised or sponsored meetings, book reviews and a diary on worldwide hydrology-related events.

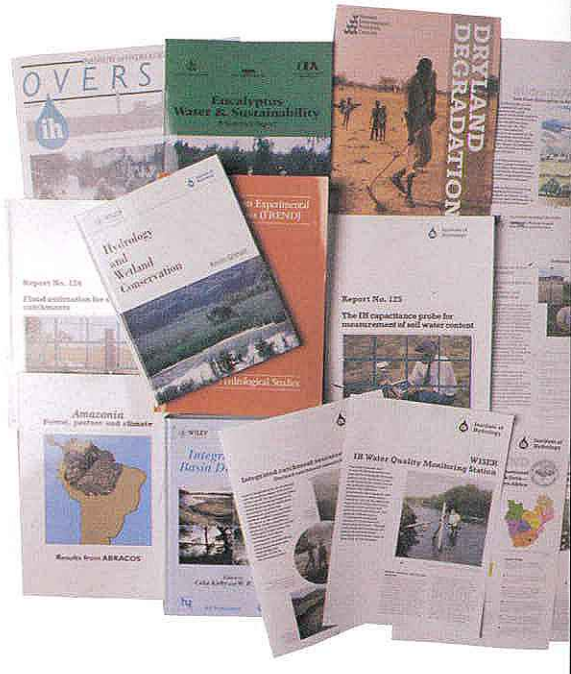
Contact: Penny Kisby

"Scientific research is only as good as the dissemination of the results." So said Christopher Patten when he was Minister for Overseas Development and it is a sentiment taken very seriously by the Institute. During the year we have continued to ensure the effectiveness of technology transfer between research scientists and our user community, always bearing in mind each particular audience and their special needs. Several lengthy research reports, technical brochures and specialist leaflets have been produced as well as continuing production of high-calibre audio visual aids for scientists presenting material to international audiences.

Conferences, symposia and seminars are the traditional fora for the exchange of knowledge within the scientific community and we were pleased to organise a highly successful international meeting in the Lake District during October 1994 on *Ecosystem Manipulation Experiments* on behalf of the Commission of the European Communities and with financial assistance from Environment Canada. Both the oral papers and the poster presentations were subsequently edited at Wallingford for publication in the CEC series as Ecosystems Research Report No. 20. This followed rapidly on the heels of an international conference on Integrated River Basin Development, organised jointly with HR Wallingford and co-sponsored by ODA. Papers presented at this September meeting were published by John Wiley & Sons Ltd (ISBN: 0-471-95361-X).

Links with post-graduate courses have continued, with visits from several UK MSc courses and overseas including students from the universities of Freiburg and Wageningen.

Information services



Support for professional hydrologists is provided through the Institute's links with the British Hydrological Society, with the editing and production of the society's quarterly newsletter and Occasional Papers series.

We have a good rapport with both local press, radio and television outlets and also the science correspondents of the national papers, to the extent that every time the weather displays unseasonable traits, we field a large number of calls seeking professional comment, greatly in demand because of our expert position and our impartial viewpoint.

Contact: Celia Kirby

1994/95 Highlights

Partitioning of water resources is a key component of the Middle East peace process. The facilities of the National Water Archive have been used to help resurrect the Lebanese River Flow Archive and allow a very valuable information resource to be fully exploited.

Licensing of IH spatial data holdings continues to grow. A new user of the data is the Countryside Council for Wales who lease the 1:50000 digital rivers. This set, the IHDTM and the Flood Studies Report datasets can be supplied in most popular formats and on most magnetic media.

HYDATA has been established in each of the ten southern African countries participating in the FRIEND project. This has involved provision of HYDATA, training in its installation and use, and assistance in loading national datasets.

SWIPS, a database and analysis package for storing soil moisture data from a variety of instruments, is now available.

The feasibility of mapping floodplain boundaries has been studied in conjunction with a major insurance broker. Further to this, work with the British Geological survey has involved preliminary investigations into a digital terrain model suitable for the hydraulic modelling of the flood plain.

Transfer of time-series chemistry can be problematical. A generic system for this has been designed and implemented. This system takes simple spreadsheet files used in laboratories and adds to them the extra necessary information for their easy exchange.

Sussex Ouse resource optimisation Ardingly regulating reservoir operates under complex licence conditions for refilling, local direct supply and maintenance of tidal limit abstractions. Sensitivity to those rules through historic and synthetic droughts was examined.

The acquisition, appraisal and archiving of a number of hitherto neglected lengthy river flow records has provided the research community with an important perspective on long-term runoff variability. A monthly series for the Wendover springs — the longest extant record in the UK — provides a unique insight into hydrological conditions throughout most of the C19th.

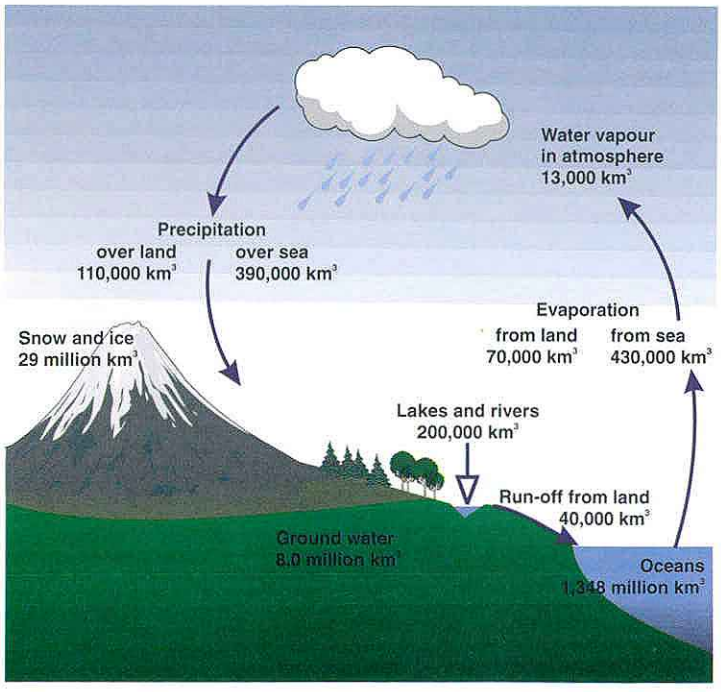
It is something of a paradox that whereas most people would claim some knowledge and concern about modern day environmental issues, they would not normally cite hydrologists as key players in the search for solutions. Hydrologists are seen as people who deal with water supply and manage reservoirs. This is but one aspect of the many facets of hydrology. Process hydrologists, concerned with the exchange of water throughout the complete hydrological cycle and the physical and biological factors which control these exchanges play a major part in NERC's advance of hydrological sciences.

Hydrological Processes

WHAT ARE HYDROLOGICAL PROCESSES ?

Jim Wallace

It is not the vast quantities of water which are held in the oceans and on the land which are significant, since it is almost always either saline or inaccessible. Rather, it is the changes in these quantities brought about by the fluxes of precipitation, evaporation and runoff between these vast reservoirs which matter.



These fluxes are orders of magnitude smaller than the total storage, but fundamentally sustain all life forms on earth. Process hydrology is concerned therefore with the study of the land surface factors which affect rates of precipitation, evaporation and runoff Our ability to accurately describe these rates over realistically complex and heterogeneous terrain is still extremely limited and is one major drives in IH research.

Human perception of environmental problems tends to change like fashion. Currently, great interest is focused on climate change, yet it is not long since we were encouraged to worry about global winters and new ice ages. Acid rain was perceived as the scourge of Europe a decade ago and despite heroic efforts to reduce SO_2 emissions from coal burning power stations, this environmental problem has not been 'solved', it simply became less fashionable and attention moved on to the next (more fashionable)

problem. It is arguably possible to make defensible links between hydrological processes and almost any current environmental issue — our climate is after all much more dependant on the water vapour in our atmosphere than any of the other 'greenhouse' gases.

Fundamentally, since water is the life blood of the entire earth system, we need to know about the exchange between the vast reservoirs stored in the land and sea if we are to cope with most current environmental problems, understand the past and anticipate the future.

Whereas fashions come and go, there is an underlying constancy to the approach required to sustain the development of hydrological process science so that the techniques and information are available for application to the next environmental problem. Most progress has been made by the combination of experimentation — making measurements of rates of precipitation, evaporation or runoff — with developing models which can adequately explain these observations.

This basic principle defines the type of approach and skills required to sustain the development of this science. Instruments continue to be needed to allow the necessary measurements to be made. For example, the neutron probe, developed to allow reliable and routine measurements of the water content of soils, has generated the data which have increased our understanding of the water use of crops and trees in a wide range of environments and led to practical models of their water requirements and growth.

Devices to measure evaporation such as lysimeters and micrometeorological instruments, have provided the information on which current understanding of the important roles that soil physical and plant physiological processes play in controlling the rate at which water vapour is transferred to the atmosphere. Modern formulae for calculating evaporation are, and continue to be, based on these observations and the insight gained from them. Since over the entire land surface of the globe around two thirds of rainfall is returned to the atmosphere as evaporation, it is not surprising that great emphasis continues to be placed on its measurement and modelling.

Having the instruments alone is not sufficient. It is also necessary to be able to deploy and maintain these instruments in many field environments. The skill and experience to do this is far from trivial and as the complexity, harshness and remoteness of the environments where data are now required become more acute, experimental skills need to be even more highly developed. Training of hydrological scientists in practical field research is therefore a fundamental and constant requirement in this area of hydrological science.

Once good, reliable observations have been sustained, hypotheses concerning the processes which control rates of exchange can be tested and 'models' of the system developed. Strictly speaking, a hypothesis or model can never be proved or 'validated'. Properly trained scientists seek observations which their current model *cannot* explain. They then refine their model to account for these new observations and proceed to obtain further data which the revised model will no longer explain.

The final essential skill required to advance hydrological process science is the ability to model exchange processes. This requires a sound understanding of the underlying physics and physiology and the mathematical skills to describe these processes in appropriate models.

Observational techniques, the skill to use these in the field and the ability to synthesise the results in models of the system under study — these are the fundamental elements which have sustained the development of hydrological process science thus far and are the basic skills which will sustain the contribution of this area of science in the future. They are invariant with fashions in environmental issues.

Global change and forecasting

Forecasting future climate is a major challenge facing environmental science. Climate responds to a range of interacting controls with a multitude of feedback mechanisms between the land surface and the atmosphere. Emerging understanding of these feedbacks, together with the very large scale nature of atmospheric processes, make experiments with Global Circulation Models (GCMs) the only feasible method of predicting future climate. GCM predictions are sensitive to representation of the land surface characteristics and, to provide accurate forecasts, require realistic parameterizations of the processes controlling the energy and water balance of the land surface. Here at IH we concentrate on complementary field measurements to derive these surface properties, while at the same time developing models and modelling techniques to use these data at a range of scales up to that of the GCM grid squares.

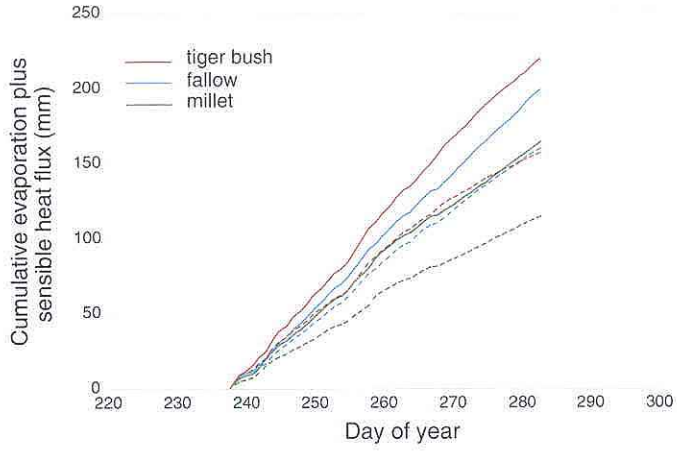
Climate change may occur through changes in the composition of the atmosphere or as a result of widespread changes in the land surface energy balance — such as those which result from large-scale vegetation change. Deforestation and desertification are two examples of changes in land use studied at IH which occur over a large enough area to produce changes in climate.

Estimating the effects of Amazonian deforestation has been one of the most active areas of application for GCMs, but the accuracy and the credibility of these predictions has been limited by the lack of data needed to establish the land surface properties of the pasture which generally replaces the forest. In ABRACOS (Anglo-BRazilian Amazonian Climate Observational Study) IH has collaborated with several Brazilian institutions to provided understanding of three pasture and forest sites across Amazonia. Some of this knowledge has already been applied to the Hadley Centre GCM giving improved estimates of the effects of deforestation. It is now predicted that deforestation would result in substantial changes in rainfall in the Amazonian basin, with the greatest change occurring around the mouth of the Amazon, outside the deforested area but where many people live and grow crops.

The Sahel is another area which is expected to be particularly susceptible to any change in global climate. IH played a central role in the HAPEX-Sahel (Hydrological and Atmospheric Pilot EXeriment in the Sahel), an international experiment designed to improve understanding of the links between land degradation and climate change in semi-arid areas.

Measurements of evaporation from three intensively monitored 'super-sites' have allowed the variation in evaporation resulting from differences in vegetation to be separated from those controlled by the distribution of rainfall and its effect on soil moisture. Differences in soil moisture have been shown to produce large short term variability in evaporation, but longer term differences in evaporation were the

Measurements of evaporation being made in a cattle ranch in Amazonia



Cumulative available energy (solid lines) (calculated as the sum of the evaporation and sensible heat flux) and evaporation (dashed lines) for the three vegetation types at HAPEX-Sahel Southern Super-Site

result of different vegetation types reflecting and emitting different amounts of radiative energy. A range of meteorological models are being used to investigate the aggregation of fluxes from the scale of the field measurements up to the GCM grid square scale.

It has long been recognised that the key to predicting the water use of vegetation is to model the behaviour of the stomata, the small apertures in plant leaves which control simultaneously their rate of water vapour loss and the rate of carbon dioxide uptake for photosynthesis. Until recently evaporation was modelled in terms of empirical functions of the controls on stomatal behaviour by atmospheric and soil variables, but increasingly it is being realised that carbon dioxide and water vapour fluxes cannot be treated as separate processes and that new models are needed which acknowledge the interdependence of these fluxes.

Work in collaboration with the Hadley Centre for Climate Prediction and Research has therefore been initiated to develop, test and calibrate combined carbon and water flux models, working towards the goal of a GCM which contains interactive vegetation, responding to changing levels of ambient carbon dioxide.

Recently, instrument technology has developed to the point where simultaneous measurements of water vapour and carbon dioxide flux can be made in the field on a routine basis, and current and future measurement programmes include the use of these devices to allow the further development and calibration of combined carbon/water flux models.

Contact: John Gash

Hydrological processes in complex vegetation

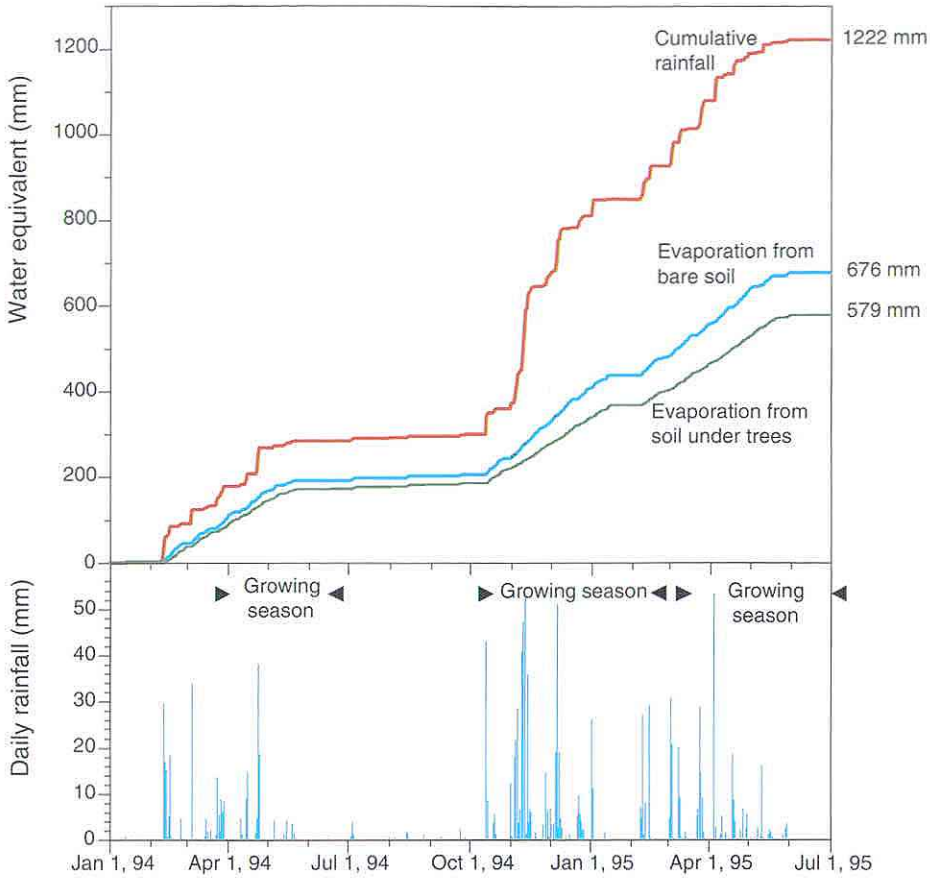
Large expanses of heterogeneous vegetative cover — particularly rainforest and savannah — have important roles in hydrological processes by virtue of the influence of their surface fluxes on the atmosphere and water balance. Loss of water from plant surfaces through stomata, i.e. transpiration, is an important process in partitioning available energy. Our ability to forecast responses of such vegetation to any kind of disturbance is often limited by lack of information and understanding about the different contributions to the total system function by individual components or groups within it, and most importantly how they each might respond to such change.

The stability of ecosystems and their tolerance of environmental stresses is related to their diversity. However, we have very poor understanding of the physiological functioning of individual species

within complex vegetation mixtures and the interaction of individual species with each other and the environment. Studies of hydrological processes in complex vegetation will contribute to understanding of their stability and hence ability to predict the response to environmental impacts.

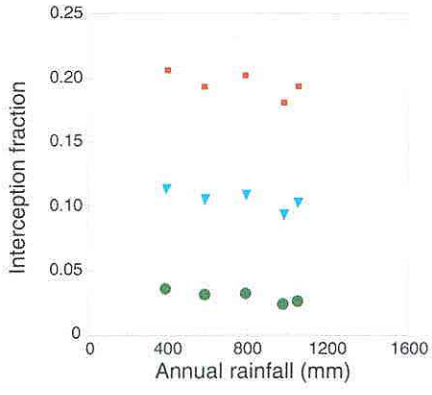
Heterogeneous vegetation dominates the land surface. Tropical rainforests, savannahs and wetlands are regarded as the most complex vegetation types but heterogeneity is not confined to natural vegetation types. Intercropping and the various forms of agroforestry such as plantations or parkland savannahs are all mixtures of species created or manipulated for the benefit of mankind. The success or failure of the many possible tree/crop options in agroforestry depends to a large extent on the degree to which components of the mixture are complementary in their use of water, light and nutrients. The measurement and modelling of water use by component species and the below-ground competition for water in agroforestry systems has a fundamental role in the planning and management of sustainable agroforestry systems.

IH is collaborating with the International Center for Research in Agroforestry (ICRAF) in Kenya and the University of Nottingham in a comprehensive experiment to examine the partitioning of light and water in a typical hill slope tree/crop mixture. Initial results show how the tree canopy can save on water lost as soil evaporation, however the introduction of trees increases interception losses. The net effect on the complete water balance of introducing trees has still to be evaluated but results from this experiment should help in assessing the utility of agroforestry systems at other sites.

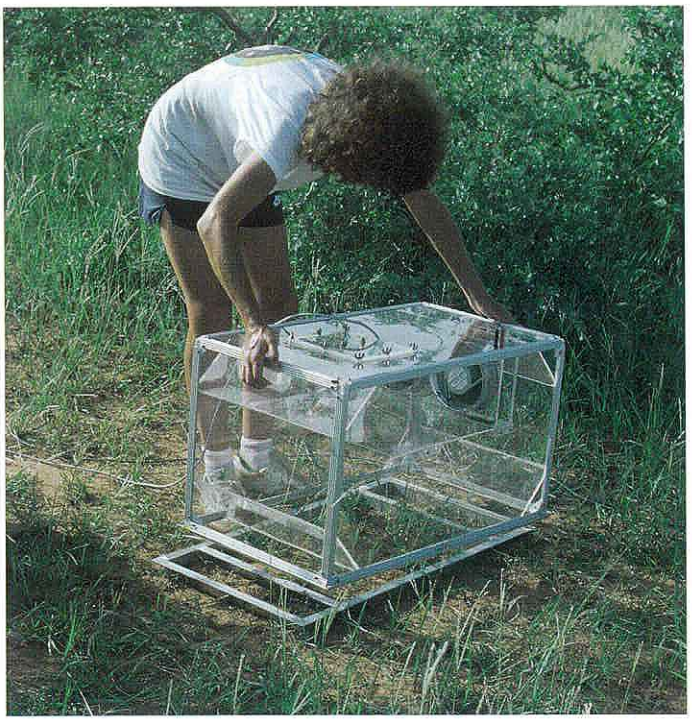


Estimated soil evaporation loss at Machakos, Kenya, in 1994/95 from a bare area and one containing trees. Over the 18-month period shown the tree shade reduces evaporation by nearly 100 mm

Complex vegetation mixtures are also studied in the ABRACOS experiment in Brazil. Here detailed measurements of stomatal conductance were made with an infra-red gas analyser throughout the complex canopies of three different rainforests across Amazonia. These observations have revealed less variation between rainforests for a particular canopy position but substantial differences between canopy positions (see right). Equally important for modelling rain forest evaporation are the consistent negative feedbacks of stomatal conductance and air dryness (humidity deficit) which is most pronounced in the species with the highest conductances. This implies that the component species have a physiological mechanism to restrict

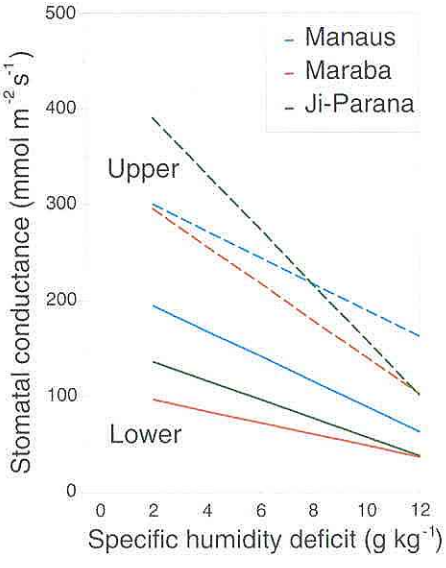


Examples of the annual fraction of rainfall lost as interception, made by using the Gash et al. *(1995) sparse forest interception model with rainfall data from 1984 to 1988 from Machakos, Kenya. Different degrees of cover are input to the model to simulate dense (100% ■), intermediate (50% ▼) and sparse (10% ●) canopies.*



Evaporation chamber in use to measure transpiration from savannah grasses

their water loss when the atmospheric demand is very high. IH have also been successful in using these detailed leaf conductance data to estimate total rainforest transpiration as well as its distribution through the canopy.



The relationship between stomatal conductance and air specific humidity deficit for an upper and lower canopy species from each of three forest sites

Mixed vegetation systems have also been studied in the Sahel. Here the separation of the transpiration and evaporation components in sparse crops and savannah has been accomplished using a range of techniques. For example, transpiration from individual savannah bushes (*Guiera senegalensis)* has been measured using the stem heat balance approach and the evaporation component from the herb and grass layer beneath the bushes has been measured using an evaporation chamber (see left). In cropped areas of the Sahel evaporation from bare soil constitutes a substantial fraction of the vapour flux from the land surface, particularly soon after rainstorms and therefore needs to be explicitly accounted for in subsequent modelling of this land type.

The success of vegetation mixtures such as agroforestry systems is dependent on the complementarity of the two or more species involved. Complementarity will be a function of both above- and below-ground competition for the resources necessary for growth. Above-ground processes, such as light interception and stomata responses, are comparatively well understood, however, below-ground processes such as the root functioning of different components of a species mixture is virtually unknown. IH is planning to use a range of tracing techniques (using stable isotopes and heat balance methods) to directly tackle the problem of obtaining water uptake data from complex multi-species root systems.

Contact: John Roberts

Sustainable natural resource management

Sustainable management of natural resources is a recurring theme in many of the conventions and policy initiatives that resulted from the UN Conference on the Environment and Development held in Rio de Janeiro in 1992. Policy makers and funding agencies alike are recognising that a more integrated approach must be taken in the management and conservation of natural resources particularly in areas where environmental degradation is already a major concern.

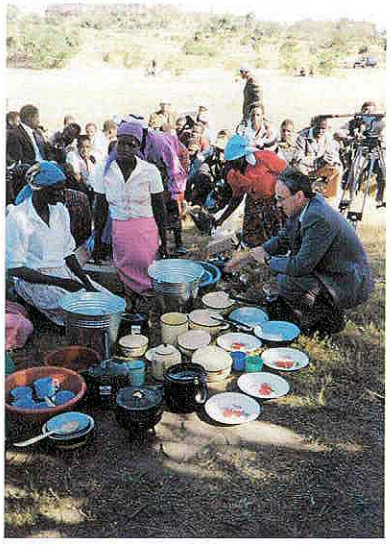
Developing methods and models for improving the management of natural resources and the sustainability of agriculture in a number of different agro-climatic zones is now a key feature of research undertaken by IH. An important feature of this work is the collaboration with other NERC institutes, HEIs and a number of overseas agricultural research institutes as well as the participation of farmers and local communities.

An example of such a project is an ODA-funded research programme in south-east Zimbabwe in collaboration with the British Geological Survey, the Lowveld Research Station and Reading University. The research within this programme has been successful in demonstrating the most efficient ways to extract and use groundwater to establish small irrigated community or allotment type gardens. To date, ten such community gardens and collector wells have been implemented as part of a pilot project. The total number of households taking domestic water from these wells is 151 and the total number of families with allotments on the associated community gardens is 731. The project has developed decision-making models that can be used in siting and designing wells and gardens and ensuring that the procedures adopted safeguard the interactive participation of local institutions and communities.

An important component of the research programme in Zimbabwe is assessing the impact of increased groundwater development on the environment, the local economy and the quality of life of rural communities. Detailed process studies are also quantifying and modelling the effects of land use and land management on groundwater recharge and the improvements in water use efficiency that can be achieved by adopting improved irrigation or rainfed farming practices. Replication of the research recommendations on a wide scale is now planned by the Government of Zimbabwe and ODA and nine NGOs have expressed interest in funding 200 extra schemes.

Another example of research to improve natural resource management involves collaboration with research groups in France, Denmark, Spain and Belgium. This project has successfully developed software that can be used for improving the tactical and strategic management of limited water resources for irrigation. The main contribution by IH has been the comparative evaluation of a number of soil water balance and crop production models. Research linked to this project has also led to the development of a model that can be used in real time for estimating soil water availability in crop root zones using daily rainfall and evaporation data as well as intermittent values of surface soil moisture obtained from remotely-sensed microwave data. This model has been shown to work well with crops that maintain complete canopy cover such as pasture.

Contact: Charles Batchelor



IH science generates wealth in many ways. Here villagers in Zimbabwe demonstrate to ODA's Permanent Secretary, John Verecker, domestic utensils purchased through sales of produce from an IH/BGS collector well community garden.

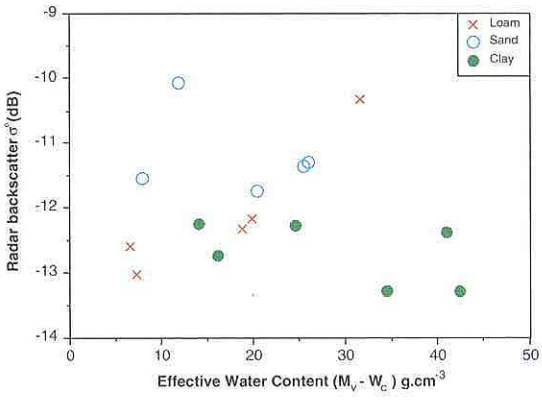
Satellite radar for soil moisture monitoring

Soil moisture plays a key role in the hydrological cycle as it is one of the most important terms which controls the transfer of energy and water between the land surface and the atmosphere, rivers and aquifers. The availability of soil moisture also determines the rate of transpiration and therefore controls the growth of vegetation. Evaporation and transpiration are the only sources of atmospheric water vapour and therefore have a crucial effect on climate dynamics. The surface soil layer is where the largest changes in moisture take place and this strongly influences energy exchange. This is also the region which may be detected by remote sensing, so the potential for monitoring soil moisture fluxes over very large areas is an exciting possibility.

The active microwave instrument on the European Space Agency ERS-1 satellite was the first satellite instrument to provide radar data for long-term Earth observation. Radar has a number of advantages over conventional sensors for the assessment of soil moisture, such as the ability to acquire data at frequent and predictable intervals thanks to its penetration of cloud. In particular, at microwave frequencies, there is a direct physical link, via the soil dielectric, between soil moisture and radar backscatter. Dry soil has a dielectric constant (ε') of about 3 whilst water has an ε' of about 80. When these two materials are mixed, the resulting dielectric constant can range from 3 (for completely dry soil) to over 25 (for wet soil). This relationship is essentially independent of ambient conditions such as temperature and illumination levels which means that soil moisture can be inferred from the radar backscatter. However, with radar other factors such as surface roughness and vegetation effects must be either quantified or minimised before soil moisture effects can be isolated.

To test the use of ERS-1 Synthetic Aperture Radar (SAR) data for monitoring soil moisture, SAR precision processed images were acquired at 35-day intervals for three test sites of sheep-grazed pasture in the UK, around 20 hectares each, selected on the basis of contrasting soils. Both automatic and manually read instruments were installed to monitor changes in surface and profile soil moisture, and vegetation was sampled at the time of satellite overpasses to determine its moisture content and bulk density.

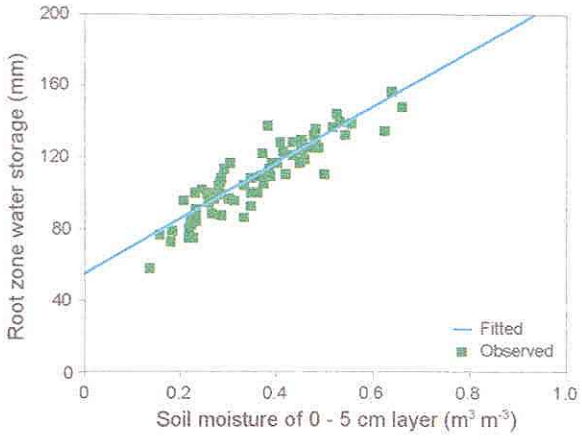
Because microwave radar frequencies only interact with the top layer of soil, an integral part of these studies has been the modelling of surface/profile soil moisture relationships which enable moisture levels within the entire root-zone region to be estimated from satellite data. The main objective has been to develop an operational system for vegetated soils that integrates the remote sensing information into a dynamic soil water balance model to obtain continuous soil moisture profiles from intermittent soil surface moisture measurements.

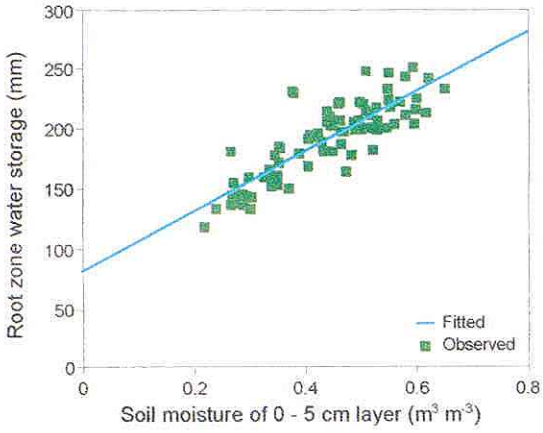


Relationship of ERS-1 satellite radar backscatter to effective soil water content over sheep-grazed pasture sites on sandy, loam and clay soils

Surface and profile soil moisture data from the ERS-1 test sites were used to test the modelling approaches which resulted in the development of an operational two-layer model. The figures on the right demonstrate the excellent agreement between the model and observed surface/profile soil moisture for both the sandy loam and clay test sites.

Contact: Ken Blyth





The relationship between root zone (0-50 cm) water storage and soil moisture content of the 0-5 cm layer of a sandy soil (above) and a clay soil (right)

1994/95 highlights

Meso-scale modelling of the Sahel A meso-scale meteorological model, with grid size of 10 km and a domain size of 1000 km by 1000 km, has been used to investigate the effects on the atmosphere of land surface variability in the Sahel. Simulations show that at the end of the dry season spatial variations of soil moisture cause significant variations in the height of the atmospheric boundary layer and circulations in the lower atmosphere.

Arctic tundra Measurements of energy and water budgets have been initiated on Svalbard island in the northern extreme of the arctic tundra. Forecasts predict that major warming will occur in these latitudes creating the possibility of additional atmospheric carbon being released by thawing of the permafrost. IH experimental data will be used to improve the modelling of this feedback on global climate change.

The stem heat balance approach has been used very successfully to distinguish rates of transpiration in different poplar clones grown as candidates for biofuels. This approach is proving well suited to continuous (10-15 days) measurements of transpiration.

Measurement of actual evaporation in Mexico A second CEC-funded project in Mexico has started with measurements of actual evaporation over irrigated cotton to check satellite estimates of potential evaporation.

Hydrological classification of dambos in Zimbabwe Satellite measurements in the thermal infrared band at high and medium resolution were used to determine the difference between surface and air temperatures. The magnitude of this difference and its temporal variation during the developing dry season indicates hydrological differences between dambo regions.

Estimation of mean annual groundwater recharge A review (for NRA) of existing practices and a comparison of models allowed nomographs to be developed for the rapid estimation of mean annual groundwater recharge at drift-free sites on the Chalk and Permo-Triassic Sandstone aquifers of England and Wales.

Mapping suspended sediments from airborne data As part of the LOIS programme, airborne spectral images are being combined with ground data to map suspended sediments and temperature in reaches of the Rivers Ouse and Trent and some of their tributaries.

Climate change and water resources (for NRA, EC and ODA). Creating climate change scenarios at a spatial scale suitable for catchment-scale hydrological studies and developing water balance models which can be applied across a large geographical domain, such as a continent.

Satellite radar for monitoring fluvial and coastal floods Severe flooding in central Europe during January 1995 was successfully recorded by the European ERS-1 satellite synthetic aperture radar and methods for improved processing and dissemination of the data are being evaluated. An EC-supported study with the Philippines Atmospheric, Geophysical and Astronomical Services Administration and Sheffield University addressed the problems of flood mapping following tropical cyclone and monsoonal rainfall events.

Soil moisture estimation using ERS-1 satellite radar A NERC Special Topic Study to determine the feasibility of modelling soil moisture from surface dielectric information recorded by satellite SAR. Instrumented test sites were used to determine the effects of soil and vegetation moisture, surface roughness and soil type on radar backscatter. Optimal modelling was developed to relate surface to profile soil moisture. Field validation measurements for the NASA SIR-C \ X-SAR Shuttle radar experiment were undertaken in Norfolk during April and October 1994.

Advances in evaporation theory Synthesis of evaporation and water balance data recorded in a number of vegetation types has led to improvements in evaporation models. For example, the control of evaporation by soil moisture supply is being examined in a new model being developed jointly with the Institute of Terrestrial Ecology. Also, the first coupled model for combining radiation, interception and transpiration in mixed species has been developed. This should have wide application in the broad range of mixed vegetation systems which are typical of most of the world's vegetation.

The Environmental Hydrology Division seeks to provide an understanding of the dynamics and key processes controlling pollution of surface water systems. By representing the key processes within mathematical models, our aim is to promote scientific understanding and to facilitate improved water quality and environmental management.

Environmental Hydrology

REGIONAL WATER QUALITY

Alice Robson


Environment ministers fish in troubled waters

Honesty on pollution gives British a bad name

UK still one of main polluters of North Sea

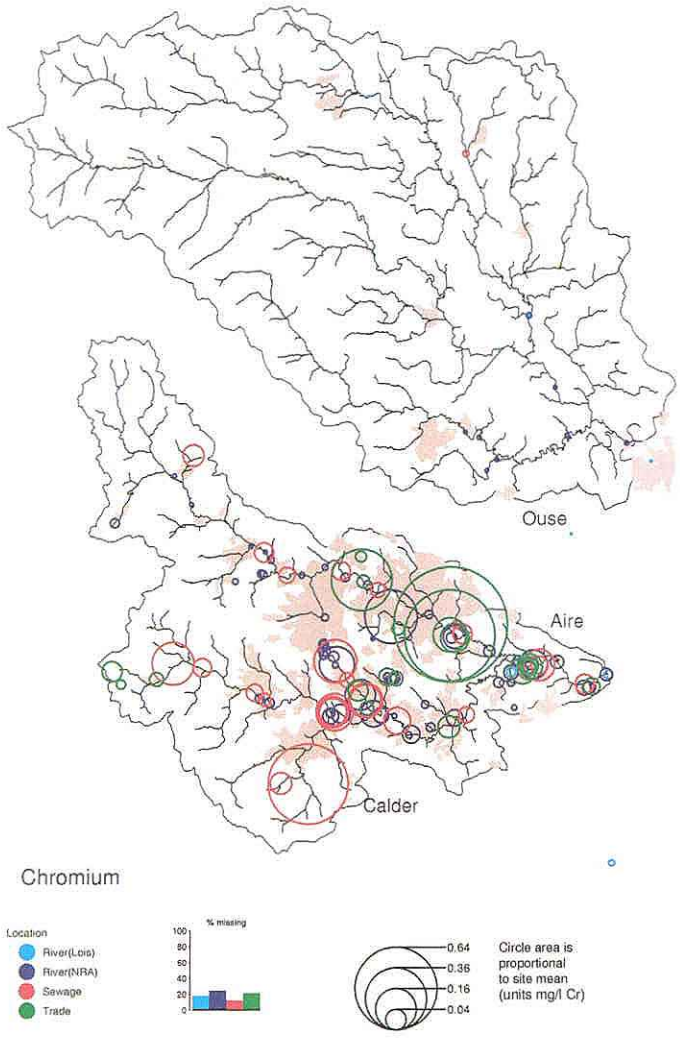
UK failing to meet pollution discharge targets

Paul Brown finds that Britain is still living up to its reputation as 'the dirty man of Europe'

UK rivers transport many thousands of tonnes of material to the oceans each year. Included in this load are anthropogenically derived pollutants such as nutrients, heavy metals and organic chemicals. These impact upon both river and ocean ecosystems and are of particular concern for confined ocean zones such as the North Sea. A major requirement in understanding such systems is the identification of riverine inputs including scenarios for land use, climatic, demographic and industrial change.

The NERC Land Ocean Interaction Study (LOIS) is at the forefront of European research into the scientific issues of controlling the North Sea environment. It aims to look at the movement of chemicals from the land to rivers, to estuaries and then out to the continental shelf and deep seas. An important component is to model river systems and examine how fluxes to the oceans may change. IH has a pivotal role in bringing together regional data and detailed studies of river processes (undertaken in collaboration with universities and other NERC research institutes) and in linking these into the modelling work.

Interpretation of regional data is crucial. Water quality data is routinely collected by the NRA regions and the Scottish River Purification Boards and the Institute is working with these authorities to explore this extensive resource. The data incorporate regional time series records of many pollutant components and include information on sewage and industrial effluents as well as river water quality. The resource is further strengthened by new field studies to provide more detailed information at strategic



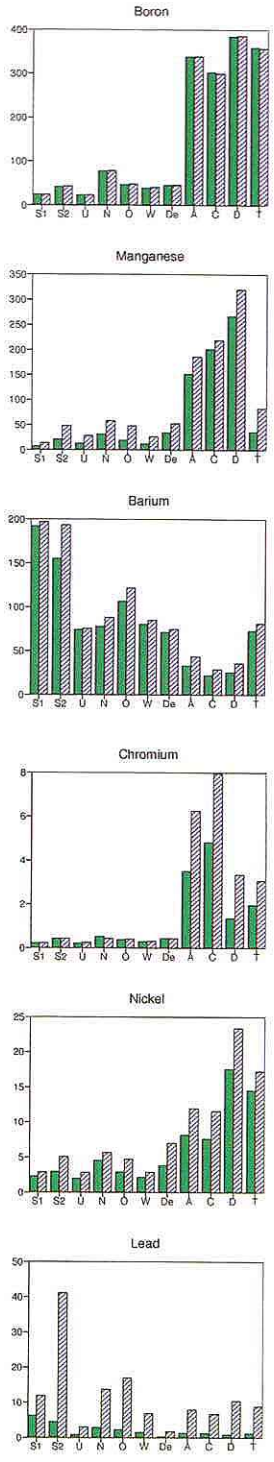
Mean river, sewage and trade effluent concentration in the Aire and Ouse catchments. Data from both NRA and LOIS sources are shown. Urban areas are shaded pink. The Aire and Calder have high levels of chromium, and numerous sewage and trade discharges relative to the rural Ouse system.

points for a wide range of pollutants. The new data will be used as the base for better estimates of flux and to describe the dynamics of chemical transfers. With measurements spread across many hundreds of sites and including over 50 chemical determinands, effective data presentation is critical to practical regional interpretation.

The LOIS study area extends from the Tweed to the Wash, incorporating a diversity of environments and related water quality issues. The region includes examples of rural areas (e.g. the Rivers Tweed, Ouse and Derwent) and highly industrialised catchments (e.g. Rivers Aire, Trent and Tyne) which have varied geologies, soil and vegetation types. From this diversity, a regional perspective on water quality issues is being developed which is a vital precursor to establishing how systems should be modelled and how water quality may change into the future.

Regional differences between the developed areas and rural catchments are striking, primarily because of significant effluent discharges from sewage works and industrial processes. There are extensive data for orthophosphate to demonstrate this, with very high levels in South Yorkshire and the upper Trent regions resulting from heavy pollutant loads deriving from cities such as Leeds, Sheffield, Derby and Birmingham. The same regional pattern of increased concentrations in the urban/industrial areas is common to many other chemical species. Metals, for example, in industrial rivers can be as much as an order of magnitude higher than the background rural level. The figure on the left presents LOIS and NRA average river water quality for chromium for two contrasting Yorkshire rivers, the Aire and the Ouse. Trade and sewage effluents are also shown. On the Ouse there are few measured sources and the ensuing river concentrations are very low (below detection limits in many cases). The Aire receives numerous effluent discharges, many very high in chromium. River concentrations increase down the course of the Aire reflecting the incremental inputs from Keighley, Bradford and Leeds. On the Calder, many of the sewage discharges are high in chromium too, especially around the Dewsbury region. The chromium in these sewage discharges is likely to be of industrial origin; although some direct trade discharges do occur, most industrial effluent is sent to sewers and treated in combination with domestic effluent.

Exceptions to the general pattern of



high concentrations in highly populated areas are illustrative of the importance of geological sources for some chemicals. For example, particulate lead is very high on the Swale due to mineralisation in the area (this is an old lead mining region). Barium too is higher in the north Yorkshire rivers and this is because of a geologically related groundwater source which is not present further south.

Although many of the industrial catchments are dominated by point source inputs, there are also diffuse groundwater and soil sources of many substances. Although the diffuse component may be comparatively small, nevertheless it is of significance when considering long term changes in water quality. Rural areas, where diffuse sources are dominant, are ideal for characterising the nature of diffuse input. Nitrate data on the Tweed show regional variations which can be linked to land use and to the hydrological characteristics of the soils. The particularly high diffuse nitrate source in the lowland arable areas relates to high fertiliser application and to runoff from slurry and silage.

Differences between industrial and rural areas extend further than the average concentrations variations presented above. Contrasting flow dynamics and chemical processes apply because the characteristics of the sources are different. More polluted rivers carry a far higher proportion of metals in particulate form because of the high particulate content of sewage effluent. This explains why less than half of the total suspended chromium in southern catchments is in dissolved form, whereas almost all chromium is in dissolved form to the north. Contrasting relationships with flow are also observed for many species. For example, nickel concentrations increase with flow on the clean upper Swale, with the dominant source from near-surface soil waters which mainly contribute during high flows. However, nickel shows a decreasing relationship with flow on the Calder: there is increased dilution of the polluting point discharges as flow increases.

Overall, LOIS has made it possible to bring together a vast amount of data so allowing fundamental questions to be resolved about regional water quality issues and the hydrochemical functioning of catchments. Further investigation can now follow of specific scientific issues such as the fate and chemical transformations of pollutant components. The study provides the basis for approaching the broader issues of how complex environments should be modelled and how environmental management and legislation can contribute to a healthy river, coastal and marine environment.

S1 = Upper Swale
S2 = Lower Swale
U = Ure
N = Nidd
O = Ouse
W = Wharf
De = Derwent
A = Aire
C = Calder
D = Don
T = Trent

Average dissolved and total metal concentrations for the LOIS monitoring sites. Dissolved concentrations are shown as solid bars, total concentrations (= dissolved + acid extractable metal) are shaded. Boron, chromium, manganese and nickel show typical patterns of highest concentrations in the southern "dirty" rivers, and lowest concentrations in the northern "clean" rivers. Barium and lead are two exceptions to this (see text). Barium has a groundwater source in the north and, apparently, few industrial sources in the south. Note that for chromium the split between total and dissolved is very different in the "dirty" rivers.

Water resource management in Nepal

A three year project investigating land use, soil conservation and water resource management in the Nepal Middle Hills has recently been completed. Hydrological aspects of this project centred on data collected from six catchments of between 2 and 5 km^2 all located within the Likhu Khola watershed to the north of Kathmandu. The data describe both the physical and the chemical aspects of the catchments' hydrology (i.e. rainfall and flow, quantities and chemistries). These data were used to study the short and long-term consequences of current agricultural practices, and the likely effects of expanding agricultural development to meet the demands of a rising population. A particular concern was that unsuitable land was being developed that would have a very limited productive lifespan and could lead to a destabilisation of a finely balanced landscape.

Current land use practices have seen the replacement of the native forest with grazing land and two types of terrace system: flooded *khet* terraces, mainly used for rice production, and gently sloping *bari* terraces used for maize, millet mustard, potato and wheat. Within the Likhu Khola the farmers and local communities were, in general, found to have adopted good land management practices, such as the use of farmyard manure to improve soil structure and increase its organic content, and the replanting and careful management of forests to maintain a valuable resource and prevent degradation.

Application of fertilizer as a side dressing

Hydrochemical studies involved the application of two water quality models. *Ricycle* is a nitrogen cycling model based on mass-balance principles and adapted to account for the appropriate nitrogen transformations within rice terraces. *Magic-Wand* is a long term lumped, process-based model of soil and water acidification. There were three main conclusions of practical use to the local farmers:

- The long-term benefits of farmyard manure application would be offset by resulting problems of soil acidification that may be further exacerbated by anthropogenic acidic oxide deposition from the atmosphere.
- Application of fertiliser as a side dressing to flooded terraces should not continue as the fertiliser is quickly washed off and is not available to promote plant growth.
- The use of ammonium sulphate as a fertiliser should be stopped, as it is likely to cause severe soil acidification problems. It should be replaced with an alternative nitrogenous fertiliser.

Complementary components of this ODA-funded project investigated the effects of land use on aquatic biology (University of Wales, College of Cardiff) and morphological studies of landslide susceptibility and gully formation (led by Queen Mary and Westfield College).

Contact: David Boorman

Hydrological and environmental impact of earthworm depletion by the New Zealand flatworm (*Artioposthia triangulata*)

The beneficial effects of earthworm activity in maintaining soil structure have long been realised. Surface and sub-surface feeders have been shown to both increase and distribute organic matter through the soil profile. Cast production and the excavation of burrows contribute to improved soil structure and profile development while surface and sub-surface casting can increase the amount of water-stable aggregates which, in turn, may decrease liability to soil erosion. The influence of soil structure on hydrological processes such as infiltration and water flow through soils may be reflected in the pore size distribution. Numbers of biopores have been directly related to total numbers of earthworms and the porosity of soils has been shown to be increased by earthworm burrows.

It is very disturbing, therefore, that the recent introduction to the British Isles of the New Zealand flatworm (*Artioposthia triangulata*) has been found to be a voracious predator of indigenous earthworm species. In a number of studies *A. triangulata* has been shown to be drastically reducing earthworm populations from observed sites. Having no natural predators in the British Isles, the spread of *A. triangulata* has been rapid since its first sighting in Belfast in 1963. Although *A. triangulata* is now most prevalent in Scotland and N. Ireland there have been some sightings in the Republic of Ireland, and increasing numbers found in England. This suggests that *A. triangulata* is progressing slowly further south and populating new areas.

The absence of earthworms has been shown to have dramatic influences on soil structure. In view of the threat posed to indigenous earthworm populations, we are assessing the indirect effects of *A. triangulata* on hydrological processes which may occur as a consequence of earthworm depletion. Potential changes in catchment hydrology could have subsequent and dramatic long-term repercussions.

Laboratory studies were conducted on soil cores taken from a three-year bin experiment conducted by the Department of Agriculture for Northern Ireland (DANI) and the Queen's University of Belfast. The bins were packed with a soil mix and had replicated treatments containing worms only (trt 2), *A. triangulata* added six months after worms were established (trt 4), and a control with no earthworms or *A. triangulata* (trt 1) — see figure on next page. Significant differences in the water release characteristic and bulk density between treatments were recorded. The figure shows the greater water holding capacity of the soil with the earthworms only, whereas the treatment with *A. triangulata* showed a similar soil structure to the control because of earthworm predation. There was also a significant increase in soil bulk density observed in the earthworm-only treatment as compared to the others. This again suggests limited structural development following the removal of earthworms by *A. triangulata*.

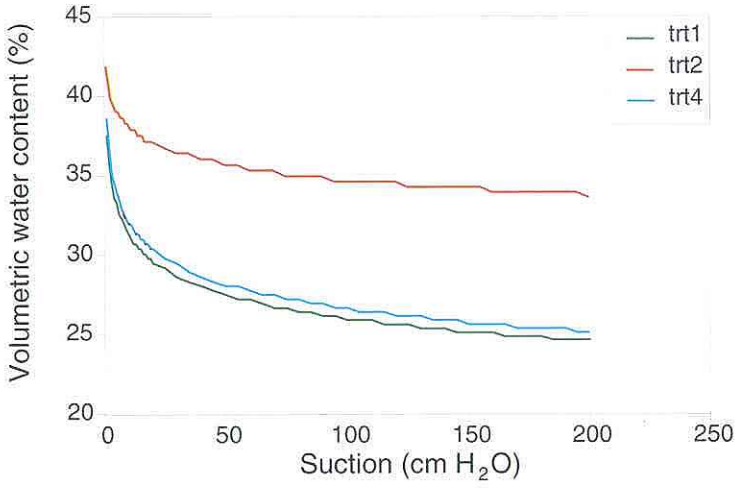
Field measurements in Northern Ireland using the CSIRO disc permeameter demonstrated differences in saturated hydraulic conductivity between sites over-run by *A. triangulata* and neighbouring unaffected sites. It now seems evident that *A. triangulata* is successful in reducing earthworm populations to a degree where soil structure and its related influence on hydrological

Saturated hydraulic conductivity measurements using a disc permeameter

properties are affected. The main conclusion of this work is that a change in earthworm activity may reduce saturated hydraulic conductivity and infiltration rates, inducing more extreme surface runoff.

A number of catchment models have already demonstrated the sensitivity of rainfall-runoff relationships to these soil hydraulic parameters. This process could well lead to environmental damage. Increased runoff may result in increased agrochemical pollution and flood hazards as more water passes directly overland to rivers and streams. In areas subject to acidification the change in flow path could be very significant. Other studies have demonstrated that increased surface or near surface runoff would greatly enhance hydrogen ion and aluminium concentrations in acidified catchments. This would increase stream acidification, impacting on fisheries and stream invertebrate populations. In heavier soils where major hydrological pathways are along macropores created by earthworms, reduced drainage may mean severe waterlogging resulting in a reduction in agricultural productivity. The severity of these hydrological changes on land use and existing agricultural practices when extrapolated to catchment scale may be extreme.

Contact: Atul Haria



Water release curves for the three treatments studied

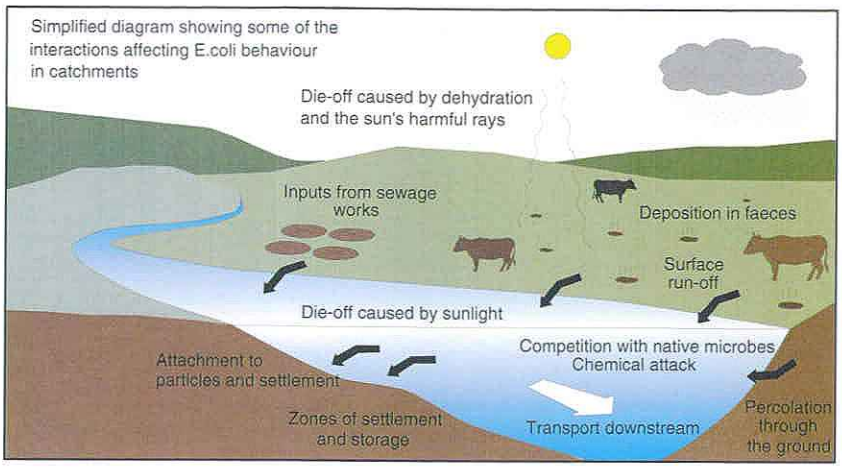
Predicting bacterial water quality

E.coli bacteria are found in the intestines of warm-blooded animals such as cows, sheep and humans. The organisms enter the natural environment when excreted in faeces and reach the river in surface runoff from rainfall, in water percolating from land adjacent to the channel, or in effluent discharges. Only a small proportion of the organisms initially released will reach the channel. The vast majority are either killed on the land surface by sunlight or dehydration, or filtered out in the soil. On entering the stream the organisms are immediately in competition with the native microbes whose hostile activity is increased at warmer temperatures. They are also under attack from their own immediate environment since sunlight falling on them damages their DNA, rendering them incapable of multiplication and both acid and alkaline waters inhibit their ability to take up nutrients and excrete wastes. The main survival strategy

available to such organisms is therefore through attachment to particles and clumping together. This can mask them from harmful sunlight and afford physical protection from preying microbes. In parts of the river where there is little turbulence, within meanders for example, the organisms attached to particles or clumped together can settle on the river bed. Following heavy rain and rising river levels, increased turbulence disturbs the stores of organisms in the bed, sweeping them back into the flow. This settlement/entrainment process may repeat a number of times before the organisms either die or are washed out into the sea.

Given this complexity, the challenge was to provide an improved method of predicting the bacterial water quality of streams and rivers. A new *E.coli* model has been developed under contract to the Department of the Environment and the National Rivers Authority with great potential for water supply protection and the estimation of bacterial loads to the coast where compliance with bathing waters regulations may be of concern.

In general, existing models for *E.coli* dynamics in rivers make certain simplifying assumptions. First, that bacterial die-off occurs at a constant rate and second, that organisms settled on the river bed can no longer affect the concentration in the water. The new model is not limited by such assumptions and has terms describing the exponential increase in *E.coli* die-off with temperature. Linear equations relate die-off to sunlight intensity, and the reduction in light penetration to the concentration of particles. The relationship with acidity (pH) uses a hyperbolic cosine law, such that die-off is a minimum at neutral pH. The model also exists in a simplified



Generalised diagram highlighting sources of E. coli, *their transport mechanisms and influence on survival on the land and in the aquatic environment*

version in which die-off is treated as a seasonal cosine function. Field experiments have shown that the wash-out of organisms from the river bed does not occur at any one threshold flow, but is a continuous process occurring over the full range of flows observed. This behaviour is achieved in the model by splitting-up the river bed storage into a large number of sub-stores which are flushed out in sequence as the flow rises. These features are incorporated into a simple river mixing model and represent a considerable improvement in the ability to simulate *E.coli* behaviour in UK streams and rivers.

Future applications include the modelling of other microbial indicators such as faecal streptococci. Application of the model to non-microbial contaminants such as heavy metals and pesticides would also be of interest. These contaminants, like *E.coli*, become attached to particles in the water and the entrainment/settlement mechanism used in this model should be of value in predicting their concentrations as well.

Contact: Jeremy Wilkinson

1994/95 highlights

Trends in surface water acidification A five-year review of the data collected as part of the DoE-funded UK Acid Waters Monitoring Network shows trends towards increasing acidity in areas most affected by acid deposition, most likely due to increased mineralisation of organic matter during the hot dry years at the start of the monitoring programme.

Assessing the role of nitrogen deposition As a major input to the UK's participation in the international negotiations on reducing acidic deposition, the dynamic model MAGIC has been further developed to assess long-term responses to nitrogen deposition.

Water source areas and flowpaths Extension of the borehole network at Plynlimon has identified the existence of dynamic and chemically variable groundwater as an important component of stream chemistry in an area classically regarded as essentially impermeable.

Pesticide movement in catchments Recently completed field monitoring has found pesticide transport to streams to be a function of flowpath, soil type and drainage. Pesticide degradation and adsorption during transport through the unsaturated zone has been found to be insignificant.

Climate change impacts First results from the climate change manipulation facility (CLIMEX) confirms a rapid and significant change in leaf gas exchange responses and increased, although not significant, stem biomass in ground vegetation.

New methodology for flood estimation Continuous simulation of runoff using the TATE and PDM models, coupled with a peaks-over-threshold analysis, has provided flood estimates in a small range of catchments, a substantial improvement on the existing design package approach.

Big basin models A number of ways of representing hydrological processes at the large scale are being explored and assembled with applications in flood hydrology (MAFF-funded), climate modelling (TIGER), and water quality (LOIS). As part of the TIGER work, a river routing model that can be applied globally has been developed and plans to implement this within coupled land-ocean GCMs are being pursued with the UK Meteorological Office.

With memories of the recent drought still prominent, water resource management in the UK, and water quantity in particular, is a key issue. Whilst climate modification, if achievable through reduced carbon emissions, remains a long-term and perhaps uncertain strategy in relation to improving water resources, it is known that the management of land use and land-use change can have direct and — in some cases — immediate impacts on the hydrological regime.

Land Use and Experimental Hydrology

MODELLING EVAPORATIVE LOSSES FROM THE UPLANDS OF SCOTLAND

David Price

Since the 1950s conifer forests in upland Britain have been identified as being responsible for increased rates of evaporation when compared with grasslands and other low vegetation covers that they often replace. The magnitude of this enhanced rate of evaporation is sufficient to lower catchment water yields and hence has economic implications for the water resource industry.

Afforestation in the Kirkton Glen, Balquhidder, Scotland

The extent of forestry in Britain is remarkably small although it is currently higher than it has been for several hundred years, covering 2.3 million hectares, which represents just 10% of the land area. At the turn of the century the coverage was only 5%. The main expansion occurred after the 1940s and has been concentrated in the uplands, primarily as a result of following a policy of afforesting only agriculturally poor ground. Conifers are favoured, and Sitka spruce in particular has gained prominence, on economic grounds, for its ability to thrive on poor upland soils in the wet UK climate. However, agricultural surpluses within the European Union have recently led to relaxation of the practice of afforesting only marginal lands and have stimulated the provision of financial incentives, in the form of Woodland Grants, for new woodland areas. This, coupled with the nation's continued requirement

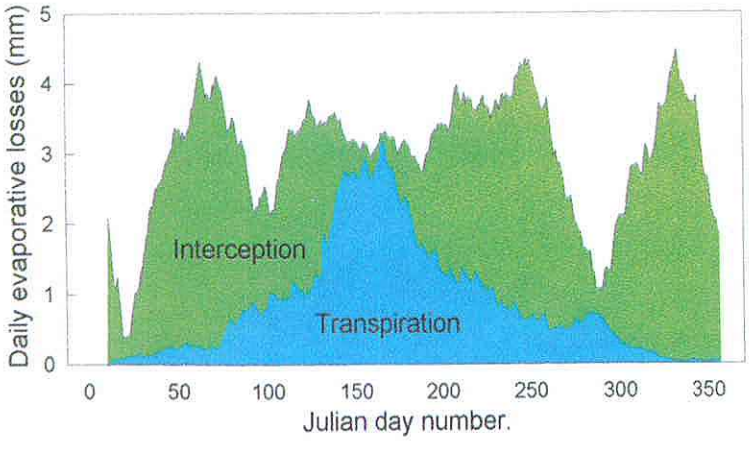
to reduce its timber imports, will probably lead to further increases in tree cover in both the uplands and lowlands of Britain.

The UK uplands are also very important to the nation's water resources. These areas tend to have higher rainfall and produce relatively clean water, ideal for supply. Clearly the impact on water yield of afforestation needs to be understood and effectively managed if significant conflict between the forestry and water supply industries is to be avoided. Similar issues affect the hydro-electric industry which has an obvious financial interest in maximising the water yield from its catchments and reservoirs. The recent incentives to use non-fossil fuels have stimulated renewed interest in the potential and effective management of hydro-electric schemes.

Forestry-induced reductions in runoff from headwater catchments can have detrimental effects on the aquatic environments within their drainage networks, and have local impacts downstream on hydrologically sensitive ecosystems, such as dependent wetlands. The impact of afforestation on rivers continues to be an issue of interest to both water resource managers and environmental managers alike, and demands methodologies capable of realistically predicting likely consequences of land-use change.

Evaporative losses from forests are higher than those from low level vegetation cover such as grass, principally because of greater interception losses. Interception loss, the evaporation of precipitation water from the plant's surface, is dependent upon both the canopy's ability to "intercept" and store precipitation and its aerodynamic roughness. Differences between vegetation transpiration rates, the other main evaporation process, are smaller and tend to be less significant in the wet upland environment.

One approach followed by the Institute to determine the impact of land-use change in the uplands has been to investigate in detail the evaporation resulting from interception and transpiration processes from each of the major types of upland vegetation cover. Process studies using lysimeters, gamma ray attenuation techniques, interception sites and soil moisture monitoring were conducted at representative sites in mid Wales, north Yorkshire and at several locations in the Highlands of Scotland. Weather stations were also installed at high altitudes to improve the understanding of the variability of upland meteorological conditions. These investigations determined the evaporative characteristics of mature coniferous forest, heather, upland grass, brash and snow cover. From this a deterministic daily evaporation model related to land use was constructed. It has a minimal data requirement and can be used generally to predict evaporation from upland catchments. The model requires only estimates of daily rainfall, daily Penman potential evaporation, and snow coverage where relevant, together with the proportional coverage of each land use.



Area graph showing the predicted daily total evaporative losses for mature forest for 1992, Kirkton forest, Balquhidder. Shading indicates relative contributions from transpiration and interception

Output from the model is in the form of daily losses associated with each of the key evaporative processes for each of the different land-use types. The model can therefore be used to investigate the seasonality and magnitude of the individual evaporation processes.

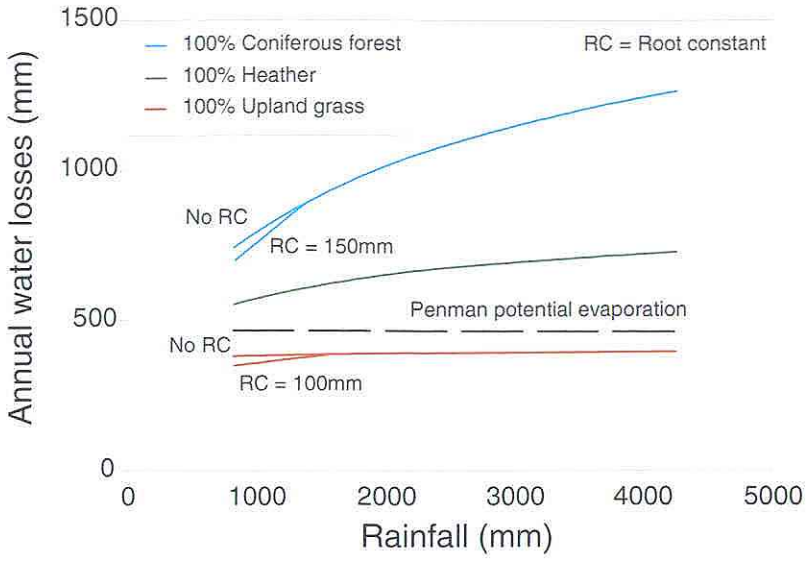
The model has now been tested over a range of Scottish climatic conditions by applying it to seven upland headwater catchments and comparing the predictions with the measured water balances, which in themselves can only provide estimates of the absolute water losses. These catchments encompass the range of rainfall patterns experienced from the drier east to the wetter western hills of Scotland, and a range of other climatic factors including potential evaporation and the probability of snow cover. During the period 1987 to 1990 the Kelty catchment and the three catchments at Loch Dee experienced average annual rainfalls of >2500 mm whilst the Girnock received little more than 1000 mm, and the Ettrick and Tima received approximately 2000 mm. The

catchments in the Southern Uplands experienced little snow, whilst the Kelty and particularly the Girnock catchment were affected by snow cover. The land uses of the catchments vary, with forest canopy coverage ranging from 0-75%.

Model predictions of the evaporative losses are shown below, together with those deduced from the catchment water balances. A good correlation is evident, providing support for the validity of the modelling approach and its usefulness as a predictive tool.

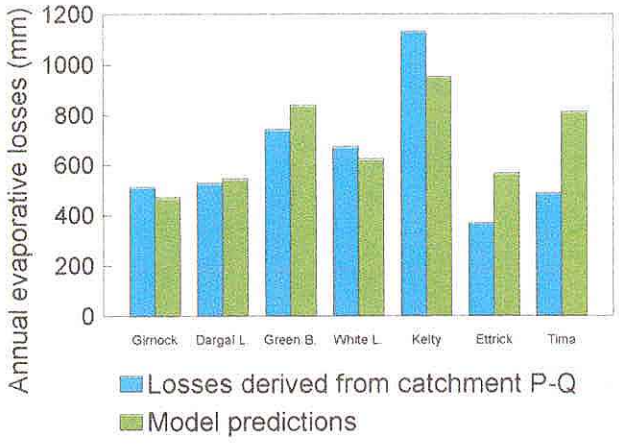
The model can also be used to assess the sensitivity of catchment evaporative losses to change in land use, either on an annual basis or on a seasonal basis to assess whether a land-use alteration may change not only the overall quantity evaporated but also its seasonal distribution. The data for the Tima catchment in the Borders of Scotland predicts an increase in evaporation of approximately 50 mm per 10% of the catchment converted from mixed moorland to forest. This rate of increase, however, is not applicable to other locations that experience different climatic conditions.

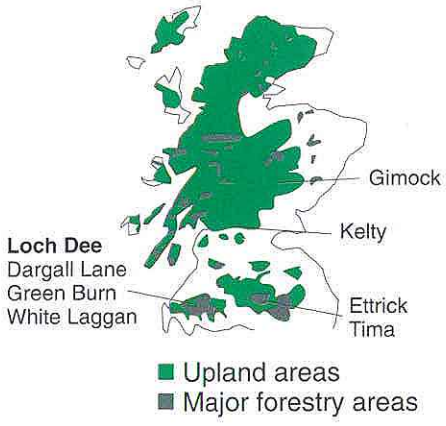
To illustrate this in more detail, the predicted evaporative losses of upland grass, heather and mature coniferous forest are shown above. Here the model is repeatedly run using rainfall input derived from an incrementally scaled rainfall data set from the IH Balquhidder field site in the central Highlands, with the simplistic assumption that the potential evaporation remains unaltered. The modelled rainfall range corresponds to that likely to be observed across the uplands of Scotland. The analysis predicts a non-linear relationship between annual losses and rainfall for forest, and that the magnitude of the losses associated with forestry are dependent upon the amount of rainfall.



Predicted annual water losses calculated over a range of rainfalls assuming constant Penman potential evaporation

The lumped deterministic model is currently being modified to allow it to run within a GIS. This will allow the convolution of the rainfall and evaporation patterns with the actual pattern of the land use which should lead to both a more general framework for operating the model and better predictions of the impacts of land use change.





Model predictions of evaporative losses compared to catchment rainfall – runoff values (3 year average, 1987-1990)

Interception losses from immature forest in northern England

Whilst there have been a number of studies of interception losses from upland forests they have concentrated on mature plantations and there is very little information available on losses from young trees. The management of commercial forest plantations has reduced the period from planting to felling, so the crop rotation may now be only 50 years. As a result, the immature forest stage is becoming a significant part (perhaps a third to a half) of the total planted area.

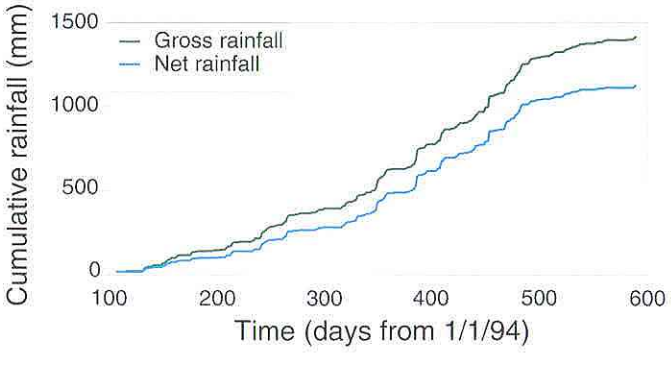
The Institute's afforestation study at Coalburn in Cumbria provides an ideal opportunity to study these losses, within a young coniferous forest under 10 m in height. In conjunction with the NRA, the Forestry Authority and North West Water plc, an interception study at Coalburn was established in summer 1994, with measurement of net rainfall (throughfall and stemflow) beneath the tree canopy. The difference between the quantity of rainfall actually reaching the ground and the total rainfall, as measured by a ground level raingauge in an unplanted area, is the amount of water intercepted on the tree canopy and then evaporated.

The choice of technique for any interception experiment will be dependent upon a number of factors. With immature trees there is much greater spatial variability in the tree canopy coverage, and hence net rainfall, than is the case for a mature closed canopy forest. It is therefore particularly important to adequately sample the net rainfall to obtain a representative average areal value. Consequently, it was decided to use large plastic sheet net-rainfall gauges capable of collecting all the stemflow and throughfall over areas of 20-50 m^2. Flows from the sheets are recorded using large (1 litre capacity) tipping buckets. In addition, an automatic weather station was installed on a tower to provide information on tree canopy climate parameters needed for detailed modelling work.

Two sites, both under Sitka spruce, were chosen with contrasting forest growth: one site with 7 m high trees and a second site with 9 m high trees. Both sites were at least 50 m from the nearest forest edge to provide representative conditions not unduly influenced by 'edge' effects. From examination of the top leader shoots, it was estimated that the growth of the trees is currently about one metre per year. Over the three-year study the trees would be expected to grow to heights of 10 m at the first site and 12 m at the second site, thus providing information on losses from trees over a total range in heights of 7-12 m.

Four interception gauges were installed, with replication under each size of tree, to determine whether variations in catch were due to the different size of the trees or simply because of random errors. Over the first year there has been good agreement between all four gauges and their response to rainfall events between measurement dates is almost identical.

The mean annual rainfall for Coalburn is about 1400 mm and is evenly distributed throughout the year. For the 12-month period under



Cumulative gross and net rainfall measured at Coalburn during May 1994 - May 1995

discussion a total of 1415 mm was recorded, compared with 1120 mm net rainfall. The annual interception loss amounted to 20% of the gross rain. This varied from about 28% in summer months (July-August) to 13% in winter (November-December).

We are finding that interception loss at Coalburn from these immature trees is much lower than has generally been reported from studies on mature trees within the UK for similar climatic conditions where annual values, typically of about 35%, have been found. The interception losses noted here amount to nearly 200 mm yr^{-1} less than expected for a mature forest. This has clear financial implications for water utilities and shows how an understanding of the hydrological effects of forestry management may help to derive an optimum overall production of wood and water from the same land.

Interception site

A modelling exercise is being carried out to determine which particular attributes of the immature forest are responsible for the reduced interception losses. Initial studies indicate that the higher aerodynamic resistance from the shorter forest is likely to be the most important determinand. However, other site factors are also being investigated which may lead to reduced interception, such as the possibility that high wind speeds enhance drainage rates from the canopy through shaking of the branches, and the possibility of cloud water deposition providing an additional input to the canopy that is not recorded by the raingauge.

Contact: Mark Robinson

Sediment transport research: high magnitude floods in the Yorkshire rivers

The sediment outputs from large scale river catchments are particularly difficult fluxes to measure as most of the sediment is conveyed downstream during a small proportion of the time, i.e. during high river flows. The monitoring of these intermittent events requires the use of a large network of automated flow-related bulk sampling, continuous turbidity measurements and manual sampling. These monitoring technologies have been integrated into the IH WISER (Wallingford Integrated System for Environmental Monitoring in Rivers) system. Real-time river flow and suspended sediment transport data provided by telemetry from the LOIS river monitoring networks in the Trent and Yorkshire rivers (see page 35) and through collaboration with the NRA, provide essential information to determine sampling strategies used by the field team based at the LOIS York Laboratory.

The flood events over the period 29 January to 3 February 1995 were the most significant flows in the Humber catchment since the field programme began in summer 1993. They provided both valuable scientific data and a test of the reliability of the monitoring technologies, checked against parallel manual sampling runs. In

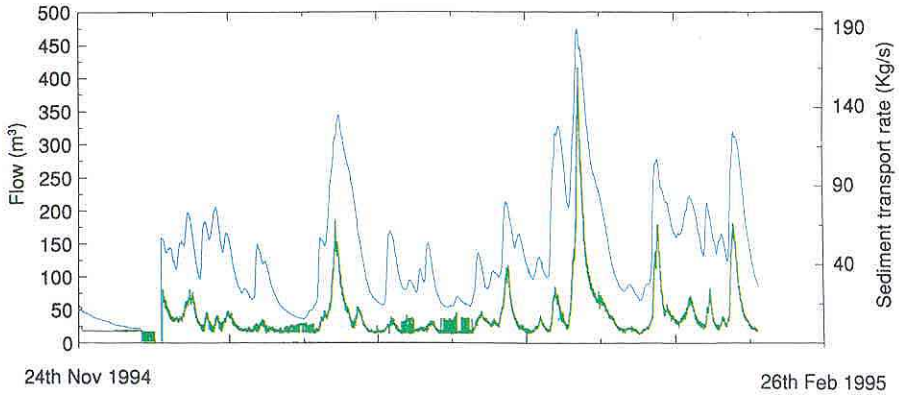
The River Beal in flood

the main, the floods consisted of a double peak. The first peak was mainly due to snowmelt from the Pennines and the second peak was triggered by a deluge of rain over the entire catchment. Data from the NRA indicated that precipitation totals at Tow Hill in the headwaters of the Ure (near Hawes) exceeded 130 mm in one 24-hour period, resulting in river flows on the Ure-Ouse system greater than the flooding of 1991, although not as great as in 1982. River discharges tended to be greater on the Ouse system for the second event (well in excess of 400 cumecs at Skelton on the Ouse), whereas the River Aire peaked during the first event. On the Ouse at York, this was the fifth largest flow event in the 120-year flow record.

During the floods, manual bulk river water samples were obtained night and day in a successful bid to cover high flows on as many of the rivers within the experimental region as possible. Continuous monitoring equipment for water chemistry and turbidity were activated during the events. Water discharge and sediment loads are shown down river on the Ouse at York. On the Swale at Leckby, samples obtained from automatic bulk samplers indicated sediment concentrations of more than 1500 mg l^{-1} at the peak of the floods. This emphasises the need to ensure good coverage of such intermittent high magnitude events, as these sediment concentrations and fluxes were much higher than any previous LOIS river measurements. An integration of calibrated turbidity record with flow data gives an overall value of 25.89 x 10^{-6} kg for sediment discharge in the Upper Swale and a very similar value for the Lower Ouse (26.89 x 10^{-6} kg) despite major inputs from the Ure, Nidd and other tributaries. This indicates a large within-channel storage component to the sediment budget, which may be very important with regard to chemical transformations and biological mediation.

There are also losses of material due to overtopping of flood embankments, recorded by vertical air photograph coverage on 2 February 1995. This survey yielded full colour stereo pairs which were processed to indicate flood coverage and combined in a GIS format with the ITE land use map to indicate areas of particular land use. The source of this material in the study catchment is being identified in a joint IH/Universities of Exeter and Coventry investigation of a range of radionuclide and geochemical suspended sediment labels.

Contact: Graham Leeks



Discharge (blue) and sediment loads (green) for the River Ouse at York

Upland wetlands, climate and water quality in Wales

During the course of the mid-Wales Llanbrynmair afforestation study (1982-present) chemical data from various streamflow sites showed larger than expected spatial variations. From the pattern of distribution it was possible to identify a considerable reduction in nutrient concentrations, acidic anions and levels of metal pollution in the Ceunant Ddu tributary of the Cwm experimental catchment as it passed through an area of riparian wetland. An intensive study of this wetland, funded by the Welsh Office, revealed that the perceived benefits inferred from the original black-box hydrochemical study were not solely due to the action of the wetland, but were also affected by the exposure of well buffered material in the base of forestry drainage lines and plough furrows in the lower part of the catchment. For some determinands, particularly nitrogen species, the benefits were not consistent and depended on prevailing climatic conditions in particular years. Nevertheless, the study was able to identify the active hydrological pathways in the catchment, and to suggest that the degree of change in streamflow chemistry was remarkable considering the small size of the wetland in relation to its feeder catchment.

The project raised two important issues: (1) climatic variability, leading to reduced wetness, may be a major control on the effectiveness of wetlands as water purifiers, and (2) there may be important links between water quality changes and gaseous losses from wetlands. However, the flow pathways within the Ceunant Ddu tributary were considered too complex for a well-controlled manipulation study, where the aim would be to elucidate the biochemical processes involved in locking up or releasing nutrients, acidic anions, associated cations and greenhouse gases in the wetland. A gully in the Wye catchment at Plynlimon, Cerrig yr Wyn, containing a discontinuous flush wetland system, was found to be hydrologically simple and therefore more suitable for such a study. The experiment was based on a novel technique of simulating predicted scenarios of climatic change, to drier or wetter conditions, by manipulating flows through small patches of wetland and monitoring the consequences for drainage water quality and gaseous emissions. The latter clearly have implications as potential feedback mechanisms for climate change through the greenhouse effect, as well as providing a 'safety valve' role for water quality.

During the simulated droughts, flow through the wetland was reduced to about a third of normal, effectively curtailing the recharge of peat from below and allowing the wetland hydrological system to split into two vertically-separated compartments. Water level deficits of up to 350 mm built up in the experimental wetland compared to 150-200mm in the control. In the first year the peat appeared to become hydrophobic on rewetting following the drought, a feature implicated in the significant suppression of emissions of methane (CH_4) from the wetland. It was perhaps expected that CH_4 emissions would decline as the wetland became more aerobic. It now appears that an additional agent inhibiting methanogenesis could be either the direct effect of increased sulphate concentrations in soil water, from oxidation of sulphides, or the associated increase in acidity.

Drying of organic soils often leads to mineralisation of nitrate (NO_3) which is then washed out in subsequent wet periods, and losses of NO_3 from the wetland followed

Flow measurement system for input of excess runoff to manipulated wetland at Cerrig yr Wyn

this rule in the first winter. While it was expected that the mineralisation of nitrogen would eventually decline over a number of years as the readily-available organic-N substrate became exhausted, the rapidity of decline in this case is unusual. This may be the result of efficient uptake of NO_3 by certain types of vegetation that were thriving in the drier conditions at the expense of pure wetland species. Alternatively, denitrification of NO_x may have increased as the bacterial population built up in response to increased available nitrate. N_2O data support the denitrification theory, as NO_x emissions were suppressed in the first year by 86% compared to the control wetland but by only 23% in the second manipulation year.

While the soil water conditions in the wetland were becoming more acidic, the reverse was happening in the streamflow. Streamflow pH increased markedly as the leaching route for sulphate removal from the body of the wetland was blocked, and as the contact time between streamflow and the more highly buffered mineral deposits surrounding the natural pipe system that drains the wetland increased. This splitting of flow pathways was also a natural dry-weather feature of the Ceunant Ddu wetland at Llanbrynmair, although the channel here was on the surface rather than sub-surface. In other respects the Cerrig yr Wyn and Ceunant Ddu wetlands behave very similarly in terms of the retention or release of ions, though the fluxes differ considerably in magnitude. Loss of phosphorus is a major exception, the Cerrig yr Wyn wetland acting as a source, possibly from soil erosion or peat wastage during the drought, and the Ceunant Ddu as an effective sink. In general, the effectiveness of the Ceunant Ddu wetland is greater, particularly as a sink for nutrients and metals, probably due to its larger size in relation to its upstream catchment.

This is a good indication that both natural and artificial riparian wetlands can be used as an agent of improved water quality. It is important however that the area of riparian wetland is reasonably large in comparison with its catchment area, and that drainage management is carried out to ensure that slope runoff is routed through the wetland ensuring maximum contact time.

Contact: Jim Hudson

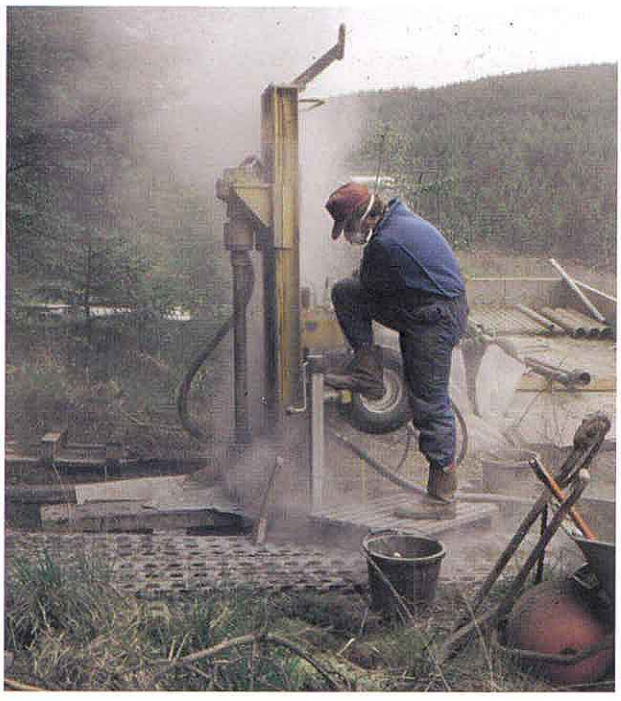
Improved drilling capability for difficult terrain

A new, lightweight, air-freightable drilling rig has been designed and built to meet the Institute's need for a rotary rig that can operate in difficult access locations both in the UK and abroad. The rig is capable of auger, air flush rotary and down-the-hole (DTH) drilling. These are the preferred methods in subsurface hydrological investigation, as water or mud flush methods are likely to contaminate the subsurface hydrological environment.

Applications for the rig are installation of deep neutron probe access tubes — techniques for which have already been developed and used at several locations — and installation of shallow groundwater monitoring wells. The rig is designed to auger drill at 150 mm diameter to 15 m depth, diamond core at 46 mm diameter to 100 m and DTH hammer drill at 100 mm diameter to 80 m depth.

The rig has been used successfully to install groundwater monitoring wells at difficult access locations within the Institute's experimental catchments at Plynlimon as part of a joint research programme funded by NERC and NRA. Used together with a trailer-mounted Pilcon Traveller 30, groundwater has been proved in all 22 wells drilled to depths of up to 45 m in mainly Silurian mudstones. This has confirmed the widespread occurrence of groundwater in fissures in the bedrock with a pH range of 4.5–6.7 (which increases by up to 1.5 pH units after dissolved carbon dioxide has degassed). Previous work on streamflow chemistry has shown that baseflow is more alkaline than quickflow. The groundwater chemistry observations seem therefore to confirm the hypothesis that the baseflow is groundwater fed. Deeper wells in these mudstones are surprisingly productive and have yielded flows as high as 300 l min^{-1} (with 0.5 m drawdown). Geophysical logging carried out by BGS as part of the joint programme has shown flow from fissuring down to depths of over 30 m.

Contact: Andy Dixon



The new IH drilling rig in operation at Plynlimon

1994/95 highlights

Surface soil water The Surface Capacitance Insertion Probe (SCIP) has undergone testing, both in-house and by selected observers overseas. This has included the use of the probe to produce ground truth data for surface soil dielectric constant and water content to compare with remotely-sensed observations by the ERS-1 satellite. Work is proceeding on characterising probes in terms of dielectric constant and soils in

the same terms to produce a series of probe-independent calibrations, as well as providing a link with other dielectric-based methods for measuring water content, such as Time-Domain Reflectometry.

IH capacitance probes used to calculate SMD An Automatic Soil Water Station (ASWS) at Wallingford uses probes at 5, 15 and 50 cm depths to estimate the soil moisture deficit, integrated over a depth of one metre. Percentage volumetric water deficits at each depth are determined and compared with other measurements (gravimetric, neutron probe) and with MORECS estimates. These data are now disseminated via the monthly Hydrological Summary for Great Britain (available from the Institute: contact Shirley Black).

Water quality instrumentation WISER (Wallingford Integrated System for Environmental monitoring in Rivers) systems are capable of logging key water quality data (including pH, electrical conductivity and turbidity). Automatic sampling, with programmable triggering routines, is a further feature. Many units have been deployed in the LOIS programme and at Plynlimon. Telemetry allows the units to be interrogated remotely.

Atmospheric H_2O/CO_2 flux instrumentation has been recently developed, using a LiCor closed-path infra-red gas analyser and Solent 3-D ultrasonic anemometer to measure CO_2 and water vapour fluxes. These are closely linked through plant transpiration. One system is being installed in Svalbard in the Arctic Circle and another in the Amazon rainforest. The results will be of value in furthering knowledge of links between climate change and the hydrological cycle.

ASWS measures flood hazard (for NRA). The Institute's Automatic Soil Water Station, reported extensively in last year's Annual Report, has been used to investigate further the relation between soil water content and flood hazard in a clay-dominated catchment. Nearly five station-years of soil water content data have been collected. Using measured soil water content at 0.15 m depth as an input to the IHACRES model, the predictive accuracy of the rainfall-runoff model improved and the period of calibration data required reduced markedly.

Catchment consultancy work in Chile (for ODA). IH has been subcontracted to give advice on the selection, instrumentation and operation of a number of trial catchment studies whereby Newcastle University will transfer SHE model technology to the Chilean forest service, CONAF.

International links The Institute participates closely in the European network of Representative and Experimental catchments which covers many countries in western and central Europe. A successful conference on Temporal Variability in Hydrology was held at Barcelona University in the autumn 1994.

"Septum" tensiometers Testing of septum stoppered tensiometers shows they operate under a wide range of soil water conditions, eliminating the need for mercury filled manometers in many situations.

Jersey catchment study A model to predict groundwater recharge and streamflow response in Jersey is being developed and tested on the accumulating data from this catchment. An aerial survey of land use was carried out in May 1994 and the monitoring network has been expanded to include automatic stream water quality sampling.

Hydrological impact model for Sri Lanka Experimental studies initiated in 1993 have continued at two hydrologically distinct regions within the Mahaweli Catchment. The data are being used to calibrate a process-based hydrological impact model and will be linked to a GIS as an aid to rationalising land-use planning and reforestation in the area.

IH Plynlimon staff commissioned by Powergen plc to study flood risk in the catchment of the Nant y Moch reservoir, mid-Wales. There was a need to update risk assessments using the *Flood Studies Report* techniques and incorporating hydrometric data (mainly rainfall) that had become available since the dam was originally built and the operating rules defined.

Hydro-power assessment in developing countries is often hampered by a lack of local data and the difficulties of using sophisticated flow gauging techniques in remote areas. Dulas Engineering, a small firm operating in mid-Wales, together with IH Plynlimon staff, have developed a suitable gauging method using pressure

transducer water level sensors in stream sections rated by salt gulp dilution techniques. Two of the test sites were adjacent to flow gauging structures in the Plynlimon catchments and a third site at Abergynolwyn where the salt method was checked by IH using the more sophisticated, accurate and reliable technique of constant rate dilution gauging using sodium iodide.

The EC LIFE initiative provides funding for projects to demonstrate methods for improving the environment. IH Plynlimon is providing hydrological and hydrogeological expertise to Somerset County Council, the RSPB and English Nature, who are re-creating reedbed habitat in worked-out peat areas.

Impact of groundwater abstraction on wetlands in East Anglia is being studied by IH Plynlimon and the Hydrogeology Division of the British Geological survey for the Anglian Region of the NRA, in particular the connections between groundwater-fed wetlands and major aquifers. An innovative approach, based on a water budget model and a limited amount of wetland water level data, was used to predict the effect of changes in groundwater levels on wetland habitats.

Optical disdrometer-rainfall simulator studies in India and Sri Lanka have confirmed the importance of raindrop size in determining the wetting response and interception loss from forests.

Coalburn afforestation study findings have been incorporated in the latest edition of the Forestry Agency's *Forest and Water Guidelines* for woodland owners and managers.

Sediment outputs associated with timber harvesting IH has been commissioned by the NRA to measure sediment transport in forested streams in England and Wales, including impacts on channels, water quality and stream habitat.

APPENDIX 1
STAFF LIST
as at 31 July 1995

A. G. P. Debney, BSc
Director

E. J. Memish
Personal Secretary

N. R. Runnalls, MSc
– Marketing Manager

HYDROLOGICAL PROCESSES

J. S. Wallace, PhD
Divisional Head

B. A. Hawker
Personal Secretary

Global Processes

*J. H. C. Gash, PhD
- micrometeorology
R. J. Harding, PhD
- meteorologist
A. D. Culf, PhD
– boundary layer meteorology
C. R. Lloyd, BA
– evaporation physics
I. R. Wright, BSc
– micrometeorology
E. M. Blyth, MA
– climate modelling research
C. Huntingford, PhD
– climate modelling research
C. M. Taylor, MSc
– mesoscale modelling research

Vegetation and Soil Processes

J. M. Roberts, PhD
– plant physiology, transpiration
S. J. Allen, PhD
– evaporation from semi–arid vegetation
R. L. Hall, PhD
– evaporation modelling
M. G. Hodnett, BSc
– soil water fluxes
C. J. Holwill, PhD
– evaporation from semi–arid vegetation
N. A. Jackson, MSc
– water use in agroforestry systems

Sustainable Agrohydrology

C. H. Batchelor, PhD
– irrigation studies, crop water use
J. Bromley, PhD
– groundwater resources
C. J. Lovell, PhD
– soil and water conservation
R. Ragab, PhD
– soil physics modelling
H. G. Bastable, PhD
– water balance modelling
D. Waughray, MSc
– environmental economist
K. Sage
– sustainable agrohydrologist

Impacts of Global Environmental Change

G. Roberts, PhD
– surface hydrology, remote sensing
J. B. Stewart, PhD
– evaporation and radiation studies
D. S. Biggin, BA
– microwave and thermal studies
K. Blyth, MPhil
– microwave remote sensing
J. W. Finch, PhD
– groundwater and GIS
N. S. Reynard, MSc
– hydrometeorologist

ENVIRONMENTAL HYDROLOGY

A. Jenkins, PhD
Acting
Divisional Head

J. A. Champkin
Personal Secretary

Water Quality Systems

A. Jenkins, PhD
– hydrochemical modelling and assessment
D. B. Boorman, PhD
– water quality modelling
R. P. Collins, MSc
– climate change impacts on water quality
A. Eatherall, PhD
– water quality modelling & GIS
D. R. Lewis, PhD
– river quality modelling
R. Kowe, PhD
– water quality modelling
C. E. M. Sefton, BEng
– environmental modelling
M. Renshaw, MSc
– acid deposition
R. J. Wilkinson, BSc
– water quality modelling
S. Tolchard
– database and graphical support

Pollution Hydrology

R. J. Williams, BSc
– water quality modeller
A. C. Johnson, PhD
– environmental microbiologist
A. Haria, BSc
– soil physics
T. Besien, MSc
– pollution hydrologist
C. White, BSc
– pollution hydrologist

Hydrochemistry

C. Neal, PhD
– chemical hydrology
A. J. Robson, PhD
– mathematical modelling
H. Jarvie, BSc
– hydrochemistry

* The first name in each section is that of the Section Head

Analytical chemistry

C. J. Smith, LRIC
– analytical chemistry
C. L. Bhardwaj, PhD
– analytical chemistry
M. Neal, PhD
– chemical analysis, X–ray diffraction & mass spectrometry
H. A. Jeffery
– analytical chemistry
M. L. Harrow
– analytical chemistry
S. K. C. McCrorie
– analytical chemistry

Catchment Distributed Modelling

P. S. Naden, PhD
– hydrological modeller
A. Calver, PhD
– hydrological modeller
D. M. Cooper, PhD
– distributed modelling, stochastic hydrology
S. M. Crooks
– applied hydrologist
T. Spijkers, MSc
– hydrologist
P. Broadhurst, MSc
– mathematical modeller
B. Gannon
– hydrologist

ENGINEERING HYDROLOGY

A. Gustard, PhD
Acting
Divisional Head

S. Smith
Acting Personal
Secretary

Flow Regimes and Environmental Management

A. Gustard, PhD
– water resource studies and international flow regimes

African Flow Regimes

A. Bullock, PhD
– low flows
M. P. McCartney, MSc
– low flow estimation
A. J. Andrews, BSc
– low flows & GIS

Low Flow Hydrology

A. R. Young, MSc
– low flows; water resources
H. G. Rees, MSc
– European database manager; FRIEND
A. E. Sekulin, MSc
– hydrological programmer
J. M. Dixon
– hydrologist; Welfare Officer
K. M. Irving, BSc
– low flows; artificial influences
G. A. Cole, MSc
– environmental hydrologist

Hydro-ecological Modelling

C. R. N. Elliott, BA
– environmental management: field studies
I. M. Gowing, HND
– environmental modelling

Flood and Storm Hazard

D. W. Reed, PhD
– hydrological extremes
D. C. W. Marshall, MSc
– engineering hydrology
E. J. Stewart, MSc
– rainfall studies
A. C. Bayliss, HND
– flood analysis
I. J. Dwyer, MSc
– mathematician
T. K. Jones, BSc
– hydrology
D. S. Faulkner, BSc
– rainfall studies
D. Jakob, MSc
– analyst

Systems Modelling

R. J. Moore, MSc
– hydrological forecasting, weather radar, stochastic hydrology
D. A. Jones, PhD
– stochastic hydrology & forecasting
R. M. Austin, MSc
– hydrological forecasting and control
V. A. Bell, PhD
– distributed forecasting
D. S. Carrington, MPhil
– weather radar studies

Water Resource Systems

F. A. K. Farquharson, MSc
– overseas contracts, flood estimation
R. B. Bradford, MSc
– groundwater resources management
J. R. Meigh, PhD
– water resources and flood estimation
J. C. Packman, MSc
– urban hydrology
K. J. Sene, PhD
– hydrological modelling, evaporation estimation
H. A. Houghton-Carr, MSc
– flood estimation; real-time forecasting
V. J. Bronsdon
– hydrological assistant; cartographer
J. P. Moores, MSc
– water resources; hydrological impacts
F. Cecil
– hydrological assistant; cartographer

INFORMATION HYDROLOGY

F. M. Law, BSc
Divisional Head

S. J. Beresford
Personal Secretary

National Water Archive

M. L. Lees, BSc
– Archive Manager
T. J. Marsh, BSc
– editor, *Hydrological Data UK* series
D. G. Morris, BSc
– Spatial Data Group manager; National River Flow Archive software coordinator
R. W. Flavin, BSc
– software developer; spatial data;
A. R. Black, PhD
– Scottish surface water archive (based at Stirling)
S. Green, BSc
– user liaison & application
O. D. Swain
– software developer
F. J. Sanderson, MSc
– hydrological monitoring; archivist
S. Black
– National Water Archive office

Hydrology Software

Y. P. Parks, MSc
– engineering hydrologist
C. M. Bottrell, BSc
– computing coordination
K. B. Black
– systems analyst
K. Down, MSc
– software development
R. D. Alexander, BSc
– software development
J. R. Parker
– documentation, sales & support

Environmental Information Systems

R. V. Moore, MSc
– digital mapping & information systems specialist
A. M. Roberts
– LOIS data management
C. I. Tindall, MSc
– LOIS (Rivers) Datacentre
C. D. Watts, MSc
– environmental scientist

Information Services

C. Kirby, BSc
Communications Manager

J. H. Griffin, MPhil
– production editor
C. L. Allen, BSc
– production editor; Press Officer
N. G. Fey, BSc
– publications assistant

Library

S. B. Wharton, BA
– librarian
D. S. Dolton
– library assistant
P. Moorhouse, BSc
– assistant librarian

IAHS Press

P. J. Kisby
– manager
F. B. Watkins, BSc
– assistant editor
P. J. Gash
– book orders

LAND USE & EXPERIMENTAL HYDROLOGY

Prof I. R. Calder,
Divisional Head;
Hydrological
Adviser
to the UK ODA

K. M. Vann
Personal Secretary

Land Use and Water Efficiency

M. Robinson, PhD
– soil water studies; streamflow generation
J. R. Blackie, MSc
– catchment studies, land-use change
H. M. Gunston, BSc
– tropical agricultural hydrology; ODA Coordinator; Training Officer
P. T. W. Rosier
– soil moisture & transpiration studies
S. A. Boyle
– soil hydrology
H. N. Davies, BSc
– hydrological measurements, data handling

Experimental Catchments

Based at Plynlimon

J. A. Hudson, BSc
– forestry impacts, catchment hydrology, hydrometeorology, water quality
K. Gilman, MA
– environmental impact, wetlands, mathematical techniques
P. J. Hill
– field measurements; process studies
S. B. Crane, BSc
– hydrometeorological data
S. Hill
– laboratory management
W. A. Hughes
– network & site maintenance

Based at Stirling

R. C. Johnson, BSc
– land-use change, snow studies, hydrometeorology, fluvial sediments
D. J. Price, MSc
– catchment hydrology, hydrometeorological data, forestry impacts

Sediment & Waterborne Fluxes

G. J. L. Leeks, BSc
– LOIS CEH programme manager; sediment transport
I. G. Littlewood, PhD
– environmental impact hydrologist
S. D. Marks, BSc
– geomorphologist; sediment studies
G. P. Ryland, MSc
– analytical chemist (LOIS)
P. Wass, MSc
– hydrology & sediment transport (LOIS)

Instrumentation

J. D. Cooper, BSc
– soil water instrumentation
A. J. Dixon, BSc
– drilling and groundwater monitoring
D. D. McNeil, BSc
– instrument development
P. Hodgson, PhD
– instrument development
R. G. Wyatt
– instrument technician
M. R. Stroud
– instrument technician
M. E. Walker
– instrument technician
J. G. Evans, BSc
– instrument development

Workshop

A. C. Warwick
– workshop manager
J. P. White
– instrument technician
G. H. Walley
– instrument technician

ADMINISTRATION

A. D. R. Gray
Head of
Administration

Financial Management & Accounts

L. A. Aspinall, BSc
– Finance Officer
A. M. Davies
– management information systems
H. G. Thomas
T. A. Gibson
A. Napper
E. A. Ostler
L. Ross, BA

Establishments & Personnel

S. A. Fenton
P. M. Sanders
V. Lambeth

Switchboard & Reception

E. Younghusband

Typing Pool

J. Hornsby
S. Smith
D. Norris
H. J. Turner

Site Services

J. R. Fraser
– site services
I. R. Standbridge
– carpenter
R. G. Drewett
– handyman/driver
J. Spencer
– caretaker/groundsman
H. V. R. Jones
– driver

Stores

J. H. Jones
– storekeeper

CASE STUDENTS

L. Bull, BSc – University of Birmingham
A. Collins, BSc - University of Exeter
J. Fisher, BSc - University of Lancaster
A. Collins, BSc - University of Exeter
S. Foster, BSc - University of Birmingham
S. Henworth, MSc - University of Southampton
K. J. Neylon, BSc - Reading University
D. A. Post, BSc - University of Lancaster
H. L. Grew, BSc - University of St Andrews

SANDWICH COURSE STUDENTS

R. Ambrose - Plymouth University
H. Bigley – University of Luton
R. Brand – University of Luton
I. Brightman – University of Luton
E. Brown– Coventry University
A. Cole – Sheffield Hallam University
C. Coulson – University of Luton
M. D. Cranston – Sunderland University
O. Highway – Coventry University
M. Hodgson – Coventry University
L. Kneeshaw – Sunderland University
N. Koria – Sheffield Hallam University
Y. O. Man – Sheffield Hallam University
S. P. McGrath – Reading University
S. J. Rollason – University of Luton
R. Stewart - Plymouth University
P. Ultsch – Oxford Brookes University

Secondment to NERC headquarters

S. C. Loader, BSc

Seconded to IUCN, Switzerland

M. C. Acreman, PhD

COMMUNITY SCIENCE & MANAGEMENT

TIGER *(Terrestrial Initiative in Global Environmental Research)*

M. A. Beran, BSc
– TIGER programme manager

H. R. Oliver, PhD
– TIGER III and TIGGER coordinator
M. Howarth
– finance & administration
S. G. Austin
– secretary

APPENDIX II
Scientific papers

Allen, S.J., Wallace, J.S., Gash, J.H.C. and Sivakumar, M.V.K. 1994. Measurements of albedo variation over natural vegetation in the Sahel. *Int. J. Climatol.* **14**, 625-636.

Arnell, N.W. 1994. Hydrology and climate change. In: Calow, P. and Petts, G.E. (eds) *Rivers Handbook.* Blackwell, Oxford. Vol. 2: 173-186.

Austin, B.N. and Cluckie, I.D. 1995. Using radar data and storm models to assist in the estimation of the probable maximum flood. *In*: British Hydrological Society Occasional Paper No. 5.

Batchelor, C.H., Lovell, C.J. and **Semple, A.J.** 1994. Garden irrigation for improving agricultural sustainability in dryland areas. *J. Land Use Policy* **11**, 286-293.

Batchlelor, C.H. and Soopramanien, G.C. 1994. Water use and irrigation control of drip-irrigated sugar cane. Proc. 5th International Micro-irrigation Conference. ASHE Publications.

Batchlelor, C.H., Lovell, C.J., Murata, M. and McGrath, S.P.M. 1995. Improving water use effectiveness by subsurface irrigation. *Aspects of Appl. Biol.* **38**, 269-278.

Bell, V.A. 1994. Thin film flows with evaporation. PhD thesis, University of St.Andrews. 149 pp.

Bell, V.A. and **Moore, R.J.** 1994. A distributed flood forecasting model using weather radar and digital terrain data. *Ann. Geophsicae* **12**, supp. II, C393.

Black, A.R. 1994. Seasonality of Flooding in the White Laggan Burn, Kircudbrightshire. *Scott. Geogr. Mag.* **110**, 162-167.

Black, A.R. and Anderson, J.L. 1994. The Great Tay Flood of January 1993. In: *Hydrological Data UK: 1993 Yearbook.* Institute of Hydrology, Wallingford. 25-34.

Blackie, J.R. 1995. The effects of conifer plantations on catchment streamflow. In: *Forests and Water 1994.* Institute of Chartered Foresters, Edinburgh, 23-43.

Blackie, J.R. and **Wilkinson, W.B**. 1995. Land use and hydrology. *The Globe* **23,** 1-4.

Blyth, E.M. and **Harding, R.J.** 1995. Application of aggregation models to surface heat flux from the Sahelian tiger bush. *Agric. For. Met.* **72**, 213-235.

Blyth, E.M., Noilhan, J. and Dolman, A.J. 1994. The effect of forest on mesoscale rainfall: an example from HAPEX-Mobilhy. *J. Appl. Meteorol.* **33**, 445-454.

Blyth, E.M. 1994. The effect of small-scale heterogeneity on surface heat and moisture fluxes. PhD Thesis, Reading University.

Blyth, E.M. and Dolman, A.J. 1995. The roughness length for heat of sparse vegetation. *J. Appl. Meteorol.* **34**, 583-585.

Bradford, R.B. 1994. Chapter 3 Baseline Monitoring: Handbook on groundwater monitoring in semi-arid countries. *UNESCO.*

Bullock, A. 1994. Hydrological studies for policy formulation in Zimbabwe Communal Areas. In: Owen, R., Verbeek, K., Jackson, J. and Steenhuis, T. (eds) *Dambo farming in Zimbabwe: water management, cropping and soil potentials for smallholder farming in wetlands.* CIFAD and University of Zimbabwe, 69-82.

Calder, I.R. 1994. *Eucalyptus, Water and Sustainability.* ODA Forestry Series No. 6, 14pp.

Christophersen, N., Clair, T.A., Driscoll, C.T., Jeffries, D.S., **Neal, C.**, and Semkin, R.G. 1994. Hydrochemical studies. In: Molden, B. and Cerny, J. (eds) *Biochemistry of Small Catchments: A Tool for Environmental Research.* J.Wiley and Sons Ltd.

Crooks, S. M. 1994. Changing flood peak levels on the River Thames. *Proc. Instn. Civ. Engrs. Wat. Marit. & Energy* **106,** 267-279.

Culf, A.D. and **Gash, J.H.C.** 1994. Comment on the paper 'Daily patterns of dew-point temperature in a semi-arid climate' by D R Butler. *Agric. For. Met.* **68**, 107-111.

Culf, A.D. 1994. Equilibrium evaporation beneath a growing convective boundary layer. *Boundary Layer Met.* **70**, 37-49.

DiGuardo, A., **Williams, R.J.**, Matthiessen, P., Brooke, D.N. and Calamari, D. 1994. Simulation of pesticide runoff at Rosemaund Farm (UK) using the SOILFUG model. *Environmental Science and Pollution Research* **1**, 151-160.

Dolman, A.J. and **Gash, J.H.C.** 1994. Tropical rainforests: hydrology and climate. In: Arntzen, C.J. (ed.). *Encyclopædia of Agricultural Science,* Vol. 4, 405-411. Academic Press Inc. Orlando, USA.

Down, K. 1994. Small size and the functioning of phototrophic Eukaryotes: studies on *Pycnococcus provasolii* Guillard 1991, (Prasinophyceae, Mamiellies). MSc Thesis, Dundee University.

Down, K., Sene, K.J. and **Parks, Y.P.** 1994. The dissemination of the HYDATA database system throughout

southern and eastern Africa. *Proceedings of Water Africa '94 Conference,* Accra, Ghana.

Dronkers, J. Herman, C., Chardy, M., **Leeks, G.J.L.** and Nolan, C. 1994. Methodology and implementation of ELOISE. In: *ELOISE (European Land-Ocean Interaction Studies) Science Plan,* Ecosystems Research Report No. 11, European Commission. Chap. 7, 38-43.

Dwyer, I.J. 1995. Correcting mean annual maxima for data disretization. *Proc. Sixth Int. Meeting on Statistical Climatology,* Galway, Ireland. 447-450.

Dwyer, I. J. and Payne, J. 1995. Flood estimation at river confluences: a review and case discussion. *Proc. 5th BHS Nat. Hydrology Symp.*, Edinburgh. 3.21-3.26.

Dwyer, I.J. and **Reed, D.W.** 1995. Allowance for discretization in hydrological and environmental risk assessment. *IH Rept. No. 123,* Institute of Hydrology, Wallingford.

Ellis, J.B., Hall, M.J. and **Packman, J.C.** 1995. Modelling water quality for urban flood storage reservoirs. *Environ. Int.* **21**, 177-186.

Fattorelli, S. Borga, M. and **Moore, R.J.** 1995. Storms, floods and radar hydrology. In: *Hydrogeological Hazards in the European Union.* 1st Review Meeting, CEC, Brussels, 30-31 January 1995. 13 pp.

Faulkner, D.S., Onaf, C.J. and Wheater, H.S. 1995. Simulating storms for flood design with a Poisson cluster rainfall model. *Ann. Geophysicae* **13**, Supp II, C532.

Finch, J.W. and **Roberts, G.** 1994. The detection of land degradation in an area of Niger, West Africa, using multi-temporal Landsat MSS images. Proc. ISPRS Commission VII Symposium, *"Resource and Environmental Monitoring"*, Rio de Janeiro.

Finch, J.W., Gliddon, D., Khamis, A. and Loughlin, W.P. 1994. Locating offshore freshwater springs in Qatar using Daedalus ATM imagery. Proc. First International Airborne Remote Sensing Conference, Strasbourg.

Fisch, G., **Wright, I.R.** and **Bastable, H.G.** 1994. Albedo of tropical grass: a case study of pre- and post-burning. *Int. J. Climat.* **14**, 103-107.

Freeman, C., Chapman, P.J., **Gilman, K.**, Lock, M.A., Reynolds, B. and Wheater, H.S. 1995. Ion exchange mechanisms and the entrapment of nutrients by river biofilms. *Hydrobiologia* **297,** 61-65.

Gilman, K. 1994. Water balance of wetland areas. In: Keane, T. and Daly, E. (eds) *The balance of water – present and future,* 123-142.

Gilman, K. 1994. Cors Erddreiniog, Anglesey - a case study in wetland conservation (North Wales). In: Patten B.C. (ed), *Wetlands and shallow continental water bodies.* Vol. 2, Case Studies. SPB Academic Publishing bv. 439-456.

Grace, J., Lloyd, J., McIntyre, J., Miranda, A.C., Meir, P., Miranda, H.S., Moncrieff, J.B., Massheder, J.M., **Wright, I.R.** and **Gash, J.H.C.** 1995. Fluxes of carbon dioxide and water vapour over an undisturbed tropical forest in south-west Amazonia. *Global Change Biology* **1**, 1-12.

Hall, R.L. and Kinniburgh, D.G. 1994. The hydrological effects of short rotation energy coppice. (HESREC) Workshop *Wood Fuel – The Green Debate,* 18-19 October, 1994.

Hall, R.L. 1995. Hydrological aspects of broadleaved woodland: implications for water supply. In: *Forests and Water, 1994.* Institute of Chartered Foresters, Edinburgh.

Hall, R.L. and Kinniburgh, D.G. 1994. Broadleaved woodland, its water use and some aspects of water quality. In: Keane, T. and Daly, E. (eds). *The Balance of Water – Present and Future,* 143-162.

Hand, D.P., Freeborn, S., **Hodgson, P.**, Carolan, A., Quan, K.M., MacKenzie, H.A. and Jones, J.D.C. 1995. Optical fibre interferometry for photoacoustic spectroscopy in liquids. *Optic Letters* **20**,

Harding, R.J., Blyth, E.M. and **Taylor, C.M.** 1994. Issues in the aggregation of surface fluxes from a heterogeneous landscape: from sparse canopies up to the GCM grid scale. Proc. SEBEX Conference, April 1994.

Hearne, J., **Johnson, I.W.** and Armitage, P.D. 1994. Determination of ecologically acceptable flows in rivers with seasonal changes in the density of macrophytes. *Reg. Rivers Res. & Manage.* **9**, 177-184.

Hermans, E. 1994. Correlation between census data and space syntax. Dissertation MSc GGIS.

Hohlov, Y.E., Howison, S.D., **Huntingford, C.,** Ockendon, J.R. and Lacey, A.A. 1994. A model for non-smooth free boundaries in Hele-Shaw flows. *Q. J. Mechanics and Appl. Maths* **47**,107-128.

Hudson, J.A., Crane, S.B. and **Robinson, M.** 1994. The impact of new plantation forestry on the quantity and time-distribution of flow in the Llanbrynmair catchments, mid-Wales. *Annales Geophysicae* **12,** Suppl. II, C429.

Huntingford, C. 1995. An exact solution to the one-phase zero-surface-tension Hele-Shaw free-boundary problem. *Computers Math. Applic.* **29**, 45-50.

Jenkins, A., Ferrier, R.C., Harriman, R. and Ogunkoya, Y.O. 1994. A case study in catchment hydrochemistry: conflicting interpretations from hydrological and chemical observations. *Hydrol. Proc.* **8,** 335-349.

Jenkins, A., Peters, N., and Rodhe, A. 1994. The hydrology of small catchments. In: Moldan, B. and Cerny, J. (eds). *SCOPE 51: Biogeochemistry of Small Catchments: A Tool for Environmental Research.* John Wiley & Sons, Chichester.

Jenkins, A., Wright, R.F., Berendse, F., van Breemen, N., Brussaard, L., Schulze, E.D., and Woodward, I. 1994. The "CLIMEX" project – using "greenhouses" to raise CO_2 and temperature in whole catchment ecosystems. *Proc. Symp. Climate change and climate change impacts,* Copenhagen.

Jones, D.A. 1994. Discussion of paper by Cheng & Taylor. *J. Roy. Stat. Soc., Series B* **57**, 30-31.

Johnson, I.W., Elliott, C.R.N. and **Gustard, A.** 1994. Modelling the effect of groundwater abstrction on almonid habitat availability in the River Allen, Dorset, England. Proc. Int. Symp. on Fish and their habitat: Methods and Applications, Lyons, France.

Johnson, A.C. and Wood, M. 1994. Sulphate-reducing bacteria in deep aquifer sediments of the London Basin: their role in anaerobic mineralization of organic matter. *J. Appl. Bact.* **75,** 190-197.

Johnson, I.W. and **Law, F.M.** 1995. Computer models for quantifying the hydro-ecology of British Rivers. *J. Instn. Wat. & Envir. Manage.* **9**, 290-297.

Johnson, R.C. 1995. Effects of upland afforestation on water resources: the Balquhidder Experiment 1981-1991, Second Edition. *IH Report 116,* Institute of Hydrology, Wallingford.

Johnson, R.C. 1994. Suspended sediment from two small upland drainage basins: using variability as an indicator of change. *IAHS Publ. No. 224,* 403-410.

Kalma, J.D. and **Calder, I.R.** 1994. *Land surface processes in large-scale hydrology.* World Meteorological Organization, Operational Hydrology Report No. 40, WMO-No. 803, 60pp.

Law, F.M. 1995. Letter to Editor concerning failure floods. *New Civil Engineer* 16 Feb issue, p.16.

Littlewood, I.G. 1994. Modelling catchment-scale water balance dynamics using long time series of rainfall, streamflow and air temperature. In: T. Keane and E. Daly (Eds.) *The Balance of Water – Present and Future*. AGMET Group Meteoroloigcal Service, Dublin, 163-173.

Littlewood, I.G. 1995. Hydrological regimes, sampling strategies and assessment of errors in mass load estimates for United Kingdom rivers. *Environment International* **21**, 211-220.

Lloyd, C.R, 1995. The effect of heterogeneous terrain on micrometeorological flux measurements: a case study from HAPEX-SAHEL. *Agric. For. Met.* **73**, 209-216.

Loader, S.C. 1994. 1993 Hydrological Diary. In: *Hydrological data UK 1993 Yearbook*. Institute of Hydrology, Wallingford. 21-24.

Lovell, C.J., Mharapara, I., **Batchelor, C.H.** and Brown, M.W. 1994. Small scale irrigation in Zimbabwe using shallow groundwater: an example of the need for integrated catchment management. *Proc. XXV Congress IAH "Water Down Under"*, Adelaide, Australia, Vol. 1, 581-585.

Lovell, C.J., Batchelor, C.H., Semple, A.J., Murata, M., Mazhangara, E. and Brown, M.W. 1994. Garden irrigation using collector wells: experiences from a first scheme in south-east Zimbabwe. In: Owen, R., Verbeek, K., Jackson, J. and Steenhuis, T. (eds). *Dambo Farming in Zimbabwe: Water management, cropping and soil potentials for smallholder farming in the wetlands*. CIIFAD, Cornell University, New York, 49-60.

Marks, S.D. 1994. Fluvial particulate inputs from afforested catchements: origins and impacts. In: Gibbins, C.N. and Turnbull, D.A. (eds) *Human Impact on Freshwater Systems: An Integrated Approach to Water Management*, Department of Environment, University of Northumbria, 1-17.

Marsh, T.J. 1995. The Chilgrove and Trafalgar Sq. boreholes. In: Herschy, R.W. (ed:) *Encyclopaedia of Hydrology and Water Resources*. Chapman and Hall, London.

Marsh, T.J. 1995. Maximising the use and utility of hydrometric data. *Proc. National Rivers Authority Seminar on Hydrometry*, Coventry, 1994.

Marsh, T.J. 1995. Yearbooks – dinosaurs or dynamos? *World Meteorological Organization Bulletin* **44**, 60-63.

Marsh, T.J. 1995. *Inland Water*. In: Digest of Environmental Statistics No. 17 (Chapter 3). Department of the Environment. HMSO, 41-48.

Marsh, T. J. (Ed.). 1994. *1993 Yearbook*. Hydrological Data UK series. Institute of Hydrology, Wallingford. 174 pp.

Marshall, B. and **Wallace, J.S.** 1994. Water and agriculture – scaling from soil grains to regions. *Proc. Fifth Int. Congress for Computer Technology in Agriculture: Enabling Technologies for land-use and resource management*, Cambridge, July 1994. Royal Agricultural Society of England. 65-68.

McCartney, M.P. and **Naden, P.S.** 1995. A semi-empirical investigation of flood plain storage on flood flow. *J. Instn. Wat. & Envir. Manage.* **9**, 236-246.

Meigh, J.R. 1995. The impact of small farm reservoirs on urban water supplies in Botswana. *Natural Resources Forum* **19**, 71-83.

Meigh, J.R. and **Reynard, N.S.** 1995. Probabilistic 8-day rainfall estimates for the snaga basin, Cameroon. *Wat. Resour. Manage.* **9**, 67-80.

Moore, R.J. 1995. Rainfall and flow forecasting using weather radar. In: Tilford, K. (ed.) *Hydrological uses of weather radar*. British Hydrological Society Occasional paper No. 5.

Moore, R.J., Hotchkiss, D.S., Jones, D.A. and **Black, K. B.**. 1994. Local rainfall forecasting using weather radar: the London case study. In: Almeida-Teixeira, M.E., Fantechni, R., Moore, R, and Silva, V.M. (eds.) *Advances in radar hydrology*. European Commission Rept EHR 14334 EN, 235-241.

Moore, R.J. and **Bell, V.A.** 1994. A grid square rainfall-runoff model for use with weather radar data. In: Almeida-Teixeira, M.E., Fantechi, R., Moore, R, and Silva, V.M. (eds.) *Advances in radar hydrology*. European Commission Rept EHR 14334 EN, 303-311.

Moore, R.J., May, B.C., **Jones, D.A.** and **Black, K.B** 1994. Local calibration of weather radar over London. In: Almeida-Teixeira, M.E., Fantechni, R., Moore, R, and Silva, V.M. (eds.) *Advances in radar hydrology*. European Commission Rept EHR 14334 EN, 186-195.

Moore, R.J. 1994. Integrated systems for the hydrometeorological forecasting of floods. In: Proc. Int. Scientific Conf. EUROPROTECH Pt I: Science and Technology for the Reduction of Natural Risks, CSIM, Udine, Italy. 121-137.

Moore, R.J., Carrington, D.S., Jones, D.A., Stewart, E.J., Hatton, R. and Aucott, L. 1994. The UK HYREX project. *Ann. Geophysicae* **12**, Suppl. II, C402.

Moore, R.J., Jones, D.A., Black, K.B., Austin, R.M., Carrington, D.S., Tinnion, M. and Akhondi, A. 1994. RFFS and HYRAD: Integrated systems for rainfall and river flow forecasting in real-time and their application in Yorkshire. *BHS Occ. Paper No. 4*.

Moore, R.J. 1995. *Weather radar and storm and flood hazard*. In: Hydrological Hazards in the European Union. 1st Review Meeting, CEC, Brussels.

Moore, R.V. 1994. The development of environmental management information systems to monitor emissions to water. *ITEMS94 Conference*, London.

Murata, M., **Lovell, C.J.** and **Batchelor, C.H.** 1994. Improving water use efficiency in garden irrigation: experiences from the Lowveld Research Station, south-east Zimbabwe. In: Owen, R., Verbeek, K., Jackson, J. and Steenhuis, T. (eds). *Dambo Farming in Zimbabwe: Water management, cropping and soil potentials for smallholder farming in the wetlands*. CIIFAD, Cornell University, New York, 39-48.

Naden, P. 1994. Core modelling of rivers in RACS (R). *LOIS Newsletter* **2**, 3.

Naden, P. 1994. Floods in large basins. *Flood and Coastal Defence*. MAFF Newsletter **5**, 5.

Parr, T. and **Eatherall, A.** 1994. *Demonstrating climate change impacts in the UK: the Department of the Environment Core Model programme 1990-1994*. Institute of Terrestrial Environment, on behalf of the Department of the Environment.

Price, D.J. and Jefferies, C. 1995. Ultrasonic doppler shift velocity measurement for river flows. *Proc. 5th BHS National Hydrology Symp., Edinburgh*, 10.23-10.28.

Prince, S.D., Kerr, Y.H., Goutorbe, J.P., Lebel, T., Tinga, A., Bessemoulin, P., Brouwer, J., **Dolman, A.J.**, Engman, E.G., **Gash, J.H.C.**, Hoepffner, M., Kabat, P., Monteny, B., Säid, F., Sellers, P. and **Wallace, J.S.** 1995. Geographical, biological and remote sensing aspects of the Hydrologic Atmospheric Pilot Experiment in the Sahel (HAPEX-Sahel). *Remote Sensing Environment* **51**, 215-234.

Ragab, R. 1995. Approaches to modelling nitrogen transformation and transport in agrosystems. Proc. of Workshop *Nitrogen Cycle in Agrosystems*, Loan, France, 6-8 April, 1994. Institut National de la Recherche Agronomique INRA, Loan Cedex, France, 56-59.

Reed, D.W. 1994. On the Gradex method of estimating extreme floods. *Dams & Reservoirs* June, 17-19.

Reed, D.W. 1994. Some notes on generalised methods of flood estimation in the UK. In: (eds) G. Rossi *et al.*

Coping with floods. Kluwer, Dordrecht, 185-191.

Reed, D.W., Rothwell, J. and **Bennett, M.C.** 1995. A study of inter-duration dependence in rainfall depths for drought severity assessment. *Ann. Geophysicae* **13**, Suppl. II, C535.

Roberts, J.M. and **Rosier, P.T.W.** 1994. Comparative estimates of transpiration of ash and beech forest at a chalk site in southern Britain. *J. Hydrol.* **162**, 229-245.

Robinson, D.A., Bell, J.P. and **Batchelor, C.H.** 1994. Influence of iron minerals on the determination of soil water content using dielectric techniques. *J. Hydrol.* **161**, 169-180.

Robinson, M. & Stamm, M.H. 1994. Soil moisture controls on streamflow behaviour. In: Llorens, P., Gallart, F. (eds) *Assessment of hydrological temporal variability and changes*. ERB Conference, Barcelona, 165-177.

Robinson, M. and **Blackie, J.R.** 1994. Small catchment studies of forest hydrology in the UK. In: Landolt R. and Gilgien, J. (eds), *Hydrology of Small Catchments*. Swiss Institute for Hydrology and Limnology, Bern. 71-82.

Sene, K.J. 1994. Land atmosphere parameterisations for a growing sparse vine crop. *Agric. For. Meteorol.* **71**, 1-18.

Sloan, W. T., Jenkins, A. and **Eatherall, A.** 1994. A simple model of stream nitrate concentrations in forested and deforested catchments in Mid-Wales. *J. Hydrol.* **158,** 61-78.

Sokhi, R., Ellis, J., Burton, D. and **Leeks, G.J.L.** (eds) 1995. Inland and Coastal Water Quality '93 - Measurement and Modelling. *Environment International*, **21** (2), 250pp.

Stewart, E.J. 1995. Spatial and temporal dependence in rainfall extremes. *Annal. Geophysicae* **13**, Supp. II, C536.

Stewart, J.B., Kustas, W.P., Humes, K.S., Nichols, W.D., Moran, M.S. and De Bruin, H.A.R. 1994. Sensible heat flux – radiometric surface temperature relationship for eight semi-arid areas. *J. Appl. Meteorol.* **33**, 1110-1117.

Stewart, J.B. and **Biggin, D.S.** 1995. Spatial variation of sensible heat flux over the HAPEX-Sahel southern super site, derived from satellite data. European Geophysical Society XIX General Assembly, Grenoble, April 1994. *Annal. Geophysicae* **12** (II), 454pp.

Stewart, J.B. 1994. Sensible heat flux derived from radiometric surface temperature for sparse prairie grass. *Proc. Symp. Thermal remote sensing of the energy and water balance over vegetation in conjunction with other sensors*, CEMAGREF-ENGREF. 23-26.

Stewart, J.B., Kustas, W.P., Humes, K.S. and De Bruin, H.A.R. 1994. Sensible heat flux - radiometric surface temperature relationship for 8 semi-arid areas. *Proc. Symp. Thermal remote sensing of the energy and water balance over vegetation in conjunction with other sensors*, 20-23 September, 1993, La Londe les Maures, France, CEMAGREF-ENGREF. 27-30.

Sutcliffe, J.V. and **Parks, Y.P.** 1994. The role of modern data processing in the Nile Basin. *Proc. Nile 2002 Conference*, Egypt.

Sutcliffe, J.V. and **Parks, Y.P.** 1995. Hydrology controls of Sudd ecology. In: Acreman, M.C. (ed.) *Hydrological management and wetland conservation*. IUCN, Geneva.

Taugbol, G. and **Neal, C.** 1994. Soil and stream water chemistry variations on acidic soils. Application of a cation exchange and mixing model at the catchment level. *Sci. Tot. Environ.* **149,** 83-96.

Twort, A. C., **Law, F.M.,** Crowley, F.W. and Ratnayaka, D.D. 1994. *Water Supply*. (Fourth Edition). Edward Arnold, London.

Wallace, J.S. 1994. Hydrological strategies: from agroforestry in Kenya to irrigated gardens in Zimbabwe: development research insights for policy makers. *Insights* **12**, 3.

Wallace, J.S. 1995. Review of "Growth and Water Use of Forest Plantations". *Agric. For. Met.* **66**, 122-126.

Wallace, J.S. 1995. Towards a coupled light partitioning and transpiration model for use in intercrops and agroforestry. In: Sinoquet, H. and Cruz, P. (eds). *Ecophysiology of Tropical Intercropping*. Guadeloupe, 1994. INRA Editions, Paris. 153-162.

Wallace, J.S. 1995. Calculating evaporation: resistance to factors. *Agric. For. Met.* **73**, 353-366.

Wallace, J.S. 1994. Hydrological processes and dryland degradation. *WMO Bulletin* **43**, 23-28.

Watts, C.D. 1994. Implementing a 4-D GIS: a utility company shows the way. *Mapping Awareness* **8**, 28-31.

Whitehead, P.G., McCartney, M.P., Williams, R.J., Ishemo, C.A.L. and Thomas, R. 1995. A method to simulate the impact of acid mine drainage on river systems. *J. Instn. Wat. & Envir. Manage.* **9**, 119-131.

Wilkinson, W.B., Neal, C. and **Leeks, G.J.L.** 1994. A review of surface water quality. In: *Environmental sedimentology: the interaction of water, sediment and waste*. PRIS, Centre for Earth and Atmospheric Sciences, Univ. of Reading. 45-48.

Wright, R. F., Cosby, J., Ferrier, R.C., **Jenkins, A.**, Bulger, A.J. and Harriman, R. 1994. Changes in acidification of lochs in Galloway, southwestern Scotland, 1979-1988: the MAGIC model used to evaluate the role of afforestation, calculate critical loads, and predict fish status. *J. Hydrol.* **161,** 257-285.

Xue, Y., **Allen, S.J., Wallace, J.S.** and Shukla, J. 1995. Calibrating a biosphere model (SSiB) for the Sahel region using SEBEX data. Abstract 3.44: European Conference on *Global Energy and The Water Cycle*, The Royal Society, July 1994

Xue, Y. and **Allen, S.J.** 1995. Testing a biosphere model (SSiB) for the Sahelian semi-arid area using field data. In: Conference on Hydrology Preprints. 75th AMS Annual Meeting, January 15-20, 1995, Dallas, Texas. American Meteorological Society, Boston. 93-98.

Zhang, J. and **Parks, Y.P.** 1994. Dynamic linking between GIS and surface water database. 5th ENVIROSOFT '94 International Conference, Development and Application of Computer Techniques to Environmental Studies, San Francisco, USA.

Zhang, J. and **Parks, Y.P.** 1994. HYQUAL and HYQUAL GIS for today and tomorrow. *Advances in Water Resources Technology and Management*, Lisbon, Portugal. European Water Resources Association.

Commissioned research reports

Andrews, A.J. & Bullock, A. 1994. Hydrological impact of afforestation in Eastern Zimbabwe. (In conjunction with the Ministry of Land, Agriculture and Water Development) *Overseas Development Administration.*

Andrews, A.J. & Bullock, A. 1994. Country Activity Reports: data collection for Southern Africa FRIEND (Feb-Aug 1994). *In association with National Hydrological Services of the SADC region.*

Anon. 1994. National system for groundwater rechange assessment. *National Rivers Authority.*

Anon. 1994. Strategic research and development needs and oportunities for real-time flood forecasting, warning and control. *Ministry of Agriculture, Fisheries and Food.*

Anon. 1994. Annual review of River Flood Protection Commission. *Ministry of Agriculture, Fisheries and Food, Flood and Coastal Defence Division.*

Anon. 1994. A flood forecasting and warning system for the River Soar: Stage 1. *National Rivers Authority Severn Trent Region.*

Anon. 1994. A flood forecasting and warning system for the River Soar: Stage 2. *National Rivers Authority, Severn Trent Region.*

Anon. 1995. The hydrological/ hydraulic investigation of the Hung Shui Kiu drainage channel. 2 vols. *Drainage Services Dept., Government of Hong Kong.*

Arnell, N. 1994. Global warming and water resources: an update. *National Rivers Authority.*

Anon. 1995. Second report of the Interagency Research Committee on the hydrological use of weather radar. *Natural Environment Research Council.*

Anon. 1994. Studies of hydrology of the Lesotho Highlands water project. Progress Reports No. 10 and 11. *Lesotho Government.*

Bayliss, A.C. On the variability of flood occurrences. *Ministry of Agriculture, Fisheries and Food.*

Bell, V.A., Carrington, D.S. and Moore, R.J. 1994. Rainfall forecasting using a simple advected cloud model with weather radar, satellite infrared and surface weather observations: an initial appraisal under UK conditions. *HYREX project, Natural Environment Research Council.*

Black, A.R., Lees, M.L. Marsh, T.J. and Dixon, J.M. 1994. A review of the Northern Ireland hydrometric network. *Northern Ireland Environment Service.*

Black, A.R., Bronsdon, R.K. and Johnson, R.C. 1995. The effects of forestry on summer low flows. *Scottish and Northern Ireland Forum for Environmental Research.*

Black, A.R., Bronsdon, R.K. and Johnson, R.C. 1995. Advice notes on the impacts of forestry, turbid waters, channel change and agriculture on river catchments. *Scottish Natural Heritage.*

Blackie, J.R. 1994. River basin management project, Chile. Report on an advisory visit during the period 10 Sept-2 Oct 1994. *University of Newcastle.*

Blackie, J.R., and Moores J.P. 1994. Land use and water resources: United Kingdom Country Paper. *Euraqua Technical Review Meeting, Wallingford.*

Blackie, J.R., McCartney, M.P., Bird, M.J. and MacDonald, A.M. 1994. The Trinity catchment study, Year I. *Jersey States Public Services Dept.*

Blackie, J.R. 1995. Instrument requirements for the river basin management project, Chile. *University of Newcastle.*

Blyth, E.M. and Harding, R.J. 1994. Preliminary investigation of the parameterisation of surface fluxes from heterogeneous land cover for the EFEDA area. *Commission of the European Communities.*

Blyth, K. 1995. Concurrent use of Radarsat and ESR-2 SAR for increased temporal monitoring of floods and soil moisture. *Canadian Space Agency.*

Boorman, D. B., Gustard, A., Gannon, B., Hollis, J.M., and Lilly, A. 1994. Hydrological aspects of the HOST classification of soils. *Ministry of Agriculture Fisheries and Food.*

Boorman, D. B. 1994. Soil water data study - Part II Use in design flood calculations: Final report. *National Rivers Authority, Anglian Region.*

Boorman, D. B. 1994. River Ythan eutrophication study: preliminary hydrological report. *Macaulay Land Use Research Institute.*

Boorman, D.B. 1994. The estimation of percentage runoff using soil water measurements on three Lincolnshire catchments. *National Rivers Authority.*

Bradford, R.B. 1994. Pumping test report for well TA6 of Dhira Wellfield, Jordan. *Sir Alexander Gibb Ltd/Arab Potash Company.*

Bradford, R.B. 1994. Ghor Safi groundwater model study. *Sir Alexander Gibb Ltd/Arab Potash Company.*

APPENDICES

Bradford, R.B. 1994. River Lavant flood study, Phase 1. Groundwater study. *Posford-Duvivier/National Rivers Authority, Southern Region.*

Bradford, R.B. 1995. Dhira groundwater model study, Phase 1. *Sir Alexander Gibb Ltd/Arab Potash Company.*

Bradford, R.B. 1995. Dhira Wellfield - Summary report on well test programme. *Sir Alexander Gibb Ltd/Arab Potash Company.*

Bradford, R.B. and Reynard, N. 1995. Climate and land use change scenarios for flood estimation in the Severn, Thames and Trent basins. *Ministry of Agriculture, Fisheries and Food.*

Bronsdon, R.K. and Johnson, R.C. 1995. The erosion of forest roads. *National Rivers Authority.*

Bullock, A. 1994. Improving the assessments of hydrological potential and yield in micro-catchment areas. (In conjunction with HR Wallingford and Asiatic Consultants Inc.) *National Irrigation Administration, Republic of the Philippines.*

Calder, I.R. and Bastable, H.G. 1994. Comments on the Malawi Government water resources management policy and strategies. *Overseas Development Administration.*

Calver, A. 1995. Continuous rainfall-runoff modelling for flood estimation. Interim report. *Ministry of Agriculture, Fisheries and Food.*

Carrington, D.S. and Moore, R.J. 1995. Extension of the London weather radar local calibration procedure to the entire Thames Basin. *National Rivers Authority, Thames Region.*

Cole, G.A. Progress Reports "Cooperation in Science and Technology with Central and East European Countries" (i) Jan-June 1994; (ii) July-Dec 1994. *Council of the European Commission.*

Dise, N. B. and Jenkins, A. 1994. The CLIMEX project: whole catchment manipulation of CO_2 and temperature. *Commission of the European Communities.*

Dixon, A.J. 1995 Record of wells installed: Langley's Lane meadow. *Drinkwater Sabey plc.*

Dixon, J.M. and Rees, H.G. 1995. Provision of river flow data to the North and Irish Seas (FRIEND). *Department of the Environment.*

Dwyer, I.J. 1995. Confluence flood joint probability. *Ministry of Agriculture, Fisheries and Food.*

Elliott, C.R.N., and Johnson, I.W. 1995. IFIM/PHABSIM scoping study: River Vyrnwy, Cound Brook, Bow Brook. *National Rivers Authority, Severn Trent Region.*

Eatherall, A. 1994. Demonstrating climate change impacts in the UK. *Department of the Environment.*

Farquharson, F.A.K., Houghton-Carr, H.A. and Parkinson, T.E. 1994. Hydrological/hydraulic investigations of the Hung Shui Kiu drainage channel: Report No. 2. *Drainage Services Dept, Government of Hong Kong.*

Farquharson, F.A.K. and Houghton-Carr, H.A. 1995. Preliminary report on development of a general integrated water resources simulation model for river basins. *Overseas Development Administration.*

Farquharson, F.A.K., Houghton-Carr, H.A. and Parkinson, T.E. 1995. Hydrological/hydraulic Investigations of the Hung Shui Kiu drainage channel: Final Report. *Drainage Services Dept. Government of Hong Kong.*

Farquharson, F.A.K. 1995. Report of Working Group on implementation, technical issues and products of WHYCOS. *World Meteorological Organization.*

Finch, J.W., Calver, A.F., Harding, R.J. and Ragab, R. 1994. National system for groundwater recharge assessment. *National Rivers Authority.*

Flavin, R.W.1994. The Severn Trent and Anglian rivers and gauging stations (two maps). *Hydropower.*

Freeman, C., Hudson, J.A. and Reynolds, B. 1994. Preliminary findings of the second field-based climate change simulation (with Institute of Terrestrial Ecology). *Welsh Office.*

Gash, J.H.C., Lloyd, C.R., Culf, A.D., Blyth, E.M. and Holwill, C.J. 1995. Surface and boundary layer measurements and upscale modelling in HAPEX-Sahel. *TIGER project. Natural Environment Research Council.*

Gilman, K. 1994. Coed Talon (Clwyd) hydrological monitoring – 1994. *Countryside Council for Wales.*

Gilman, K. 1994. Initial appraisal of hydrological aspects of the proposed re-creation of reedbed habitat at Ham Wall, Somerset. *Royal Society for the Protection of Birds.*

Gilman, K. 1994. Gauging of the Rivers Dulas and Vyrnwy using the chemical tracer dilution method. *National Rivers Authority, Severn Trent Region.*

Gilman, K. 1995. Hydrological impacts of proposed drainage improvement at Arthog Bog, Gwynedd. *Countryside Council for Wales.*

Gilman, K. 1995. Assessment of hydrological impacts of proposed borrow pit at Salbri Mire, Anglesey. *SGS Environment.*

Gilman, K. 1995. Analysis of hydrogeological evidence relating to proposed sand and gravel extraction near Vicarage Moss SSSI, Wrexham. *Countryside Council for Wales.*

Gustard, A. and Young, A.R. 1994. Scoping study to develop tools for low flow estimations. *National Rivers Authority.*

Hall, R.L., Allen, S.J., Rosier, P.T.W., Kinniburgh, D.G. and Gooddy, D.C. 1995. Hydrological effects of short rotation energy coppice. (with British Geological Survey) *National Rivers Authority.*

Hodnett, M.G. 1995. The Woburn soil moisture study. *Water Research Centre.*

Houghton-Carr, H.A. 1995. Consolidation of FSR rainfall-runoff method. Progress Report 1994/5. *Ministry of Agriculture, Fisheries and Food.*

Houghton-Carr, H.A. and Arnell, N.W. 1994. Comparison of simple conceptual daily rainfall-runoff models. *Ministry of Agriculture, Fisheries and Food.*

Houghton-Carr, H.A. and Millington, R.J. 1995. Floodplain mapping – model study of the River Frome (Gloucestershire): Hydrological study report. *National Rivers Authority, Severn Trent Region.*

Houghton-Carr, H.A. and McCartney, M.P. 1994. Tanzanian urban sector engineering project. Yield estimates for Tanga and Morogoro. *Gibb (Eastern Africa) Ltd.*

Hudson, J.A., Hill, P.J., Crane, S.B., Hughes, W.A. and Hill, T.J. 1995. The Cerrig yr Wyn wetland manipulation study. *Welsh Office.*

Hudson, J.A. 1995. Critical assessment of the proposed improvements to the meteorological observation networks in the catchment areas feeding to the Cumbrian coast in the Sellafield area. *Entec Hydrotechnica Ltd.*

Hudson, J.A., Gilman, K., Crane, S.B. and Hill, T.J. 1995. Floods in the catchment of Nant-y-Moch reservoir – implications for water level control in the reservoir and spillway design. *Powergen plc.*

Hudson, J.A. and Warwick, A. 1995. Design of a flow measuring structure for the Snowdonia Environmental Change Network site. *Countryside Council for Wales.*

Hughes, S., Hudson, J.A., Freeman, C., Hill, P.J., Hughes, W.A. and Reynolds, B. 1995. Annual report of the field-based climate change simulation. (with Institute of Terrestial Ecology). *Welsh Office.*

Huntingford, C., Blyth, E.M. and Dolman,

A.J. 1994. Land surface atmosphere interactions. *CEGB Research Fellowship report.*

Irving, K.M., Young, A.R. and Gustard, A. 1995. European atlas of small-scale hydropower resources. Proposal for Phase III (on behalf of ESHA). *ALTENER committee.*

Irving, K.M., Rees, H.G., Young, A.R. and Gustard, A. 1994. European atlas of small hydropower potential. Interim Report, *ESHA.*

Jackson, N.A. 1994. Water balance of agroforestry systems on hillslopes. *Overseas Development Administration.*

Jenkins, A. 1994. Model acidification of groundwaters in catchments – with aggregated nitrogen dynamics: Magic-wand calibration and validation. *National Rivers Authority.*

Jenkins, A. Wright, R.F. and Cosby, B.J. 1994. Modelling long-term hydrochemical response at ENCORE catchments in the UK and Norway. *Commission of the European Communities.*

Jenkins, A. *et al.* 1995. Land use, soil conservation and water resource managemennt in the Nepal Middle Hills. 2 vols. *Overseas Development Administration.*

Johnson, I.W., Elliott, C.R.N. and Gustard, A. 1994. Instream flow requirements: River Bray at Leehamford, River Barle at Perry Weir. *National Rivers Authority.*

Johnson, I.W. and Elliott, C.R.N. 1994. Workshop guide to PHABSIM (Physical Habitat Simulation System). NRA release version. *National Rivers Authority.*

Johnson, I.W. and Elliott, C.R.N. 1995. Habitat modelling and instream flow requirements: River Piddle. *National Rivers Authority , South Western Region.*

Johnson, R.C. 1994. The River Tay catchment study. *Ove Arup & Ptnrs.*

Johnson, R.C. 1995. Darwin Initiative: biodiversity in the Himalaya. *Department of the Environment.*

Johnson, R.C. 1995. Review of airborne pollution studies in the Cairngorms. *Scottish Natural Heritage.*

Johnson, R.C. 1994. Implementation of the Cairngorms ECN site. *Scottish Natural Heritage.*

Johnson, R.C., Harriman, R., Tervet, D., Lees, F. and Price, D.J. 1994. The Loch Dee and Balquhidder projects: future collaborative research. *Scottish Office Environment Department.*

Leeks, G.J.L. 1994. The effects of agricultural soil erosion upon water-courses. *National Rivers Authority.*

Lewis, D. R. 1994. LOIS Working Note No. 1: Quality assurance of flows on the River Ouse. *Natural Environment Research Council.*

Lewis, D. R. 1994. LOIS Working Note No. 3: Calculation of ungauged flows within the Ouse catchment. *Natural Environment Research Council.*

Lewis, D. R. 1994. LOIS Working Note No. 2: Use of Micro Low Flows within QUASAR. *Natural Environment Research Council.*

Loader, S. C. 1994. Significant hydrological events in the UK in 1993. *World Meteorological Oorganization.*

Lovell, C.J., Murata, M., Brown, M.W., Batchelor, C.H., Thompson, D.M., Dube, T., Semple, A.J. and Chilton, P.J. 1994. Small-scale irrigation using collector wells pilot project: Zimbabwe. 4th Progress Report. *Overseas Development Administration.*

Marks, S.D. and Leeks, G.J.L. 1994. Review of particulate outputs associated with timber harvesting and potential impacts upon water resources and aquatic ecology. *National Rivers Authority.*

Marks, S.D. and Leeks, G.J.L. 1995. The impact of particulate outputs associated with timber harvesting. *National Rivers Authority.*

McCartney, M.P. and Houghton-Carr, H.A. 1994. Hydrological review of the Kafue River, Zambia. An investigation of the potential for the Zambian Sugar Industry to abstract more water for irrigation. *Zambian Sugar Company.*

McCartney, M.P., Moores, J.P. and Blackie, J.R. 1995. The Trinity Catchment Study Year 2. Progress report on the second year of a groundwater recharge assessment project. *Jersey States Public Services Department.*

McCartney, M.P. 1994. A study of dambo hydrology in Southern Africa. *Department of Research and Specialist Services, Zimbabwe.*

McCartney, M.P. and Houghton-Carr, H.A. 1994. Hydroloigcal review of the Kafue River, Zambia. *Zambian Sugar Co.*

McCartney, M.P. and Whitehead, P.G. 1994. Modelling acid mine discharge in the Pelenna Catchment. *National Rivers Authority, Welsh Region.*

McKenzie, A.A., Gale, I.N. and Marsh, T.J. 1994. National groundwater level monitoring network review. *National Rivers Authority.*

Meigh, J.R. 1994. Water resources development project – Manual of hydrological procedures. *ELC Electroconsult/World Bank/National Irrigation Administration, Philippines.*

Meigh, J.R. 1994. Water resources development project – Task 1: Hydrological reassessment. *ELC Electroconsult/World Bank/National Irrigation Administration, Philippines.*

Meigh, J.R. 1995. Regional flood estimation methods for developing countries. *Overseas Development Administration.*

Millington, R.J. and Houghton-Carr, H.A. 1995. Floodplain mapping – model study of the River Frome (Gloucestershire). Main report. *National Rivers Authority, Severn Trent Region.*

Moore, R.J. 1994. A flood forecasting and warning system for the River Soar. *National Rivers Authority, Severn Trent Region.*

Moore, R.J. 1994. Investigation into the flood warning methodology for the River Soar. *Hydraulics Research Ltd.*

Moore, R.J. 1994. Weather radar and storm and flood hazards. *Commission of the European Communities.*

Moore, R.J. 1995. Design of radar/ raingauge networks for hydrological use. *HYREX project, Natural Environment Research Council.*

Moore, R.J., Bell, V., Roberts, G.A. and Morris, D.G. 1994. Development of distributed flood forecasting models using weather radar and digital terrain data. R&D Note 252. *National Rivers Authority.*

Moore, R.J., Austin, R.M. and Carrington, D.S. 1995. Evaluation of FRONTIERS and local radar rainfall forecasts for use in flood forecasting models: Operational Guidance Note. NRA R&D Note 387. *National Rivers Authority.*

Moore, R.V. 1995. The use of National Transfer Format for the exchange of environmental time-series data. *National Rivers Authority.*

Moore, R.V. 1995. The IH logical data model for river data. *National Rivers Authority.*

Moore, R.V., Buesst, A.W.M., Watts, C.D., Stewart, R. and Alexander, C.E. 1994. A feasibility study into a system for the assessment of an insurer's flood risk exposure (SAIFE). *International Computers Ltd.*

Moores, J.P. 1994. Sandpool Farm flood study. *Hills Aggregates Ltd.*

Moores, J.P. and Law, F.M. 1994. Confidential report on preliminary reservoir storage-yield analysis. *Rofe Kennard and Lapworth.*

Morris, D.G. and Flavin, R.W. 1995. Flood risk map for England and Wales.

Ministry of Agriculture, Fisheries and Food.

Naden, P. 1994. Modelling strategy adopted in FD412. *Ministry of Agriculture, Fisheries and Food.*

Packman, J.C., Shah, S.M.S., Wencel, K. and Ahmad, I. 1995. Urban runoff analysis & modelling – Lahore study. *Overseas Development Administration.*

Packman, J.C. 1995. The Bracknell instrumented catchment. *Ministry of Agriculture, Fisheries and Food.*

Packman, J.C. 1995. Design storms and antecedent conditions for urban drainage in the Republic of Ireland. *Integrated Hydro Systems.*

Price, D.J., Johnson, R.C. *et al.* 1994. The effects of forestry practices on water quality and biota in the Balquhidder catchments 1983-1993. *Scottish Office Environment Dept.*

Price, D.J., Calder, I.R. and Johnson, R.C. 1995. Modelling the effect of afforestation on water resources (Balquhidder). *Scottish Office Environment Department.*

Reed, D.W., Bayliss, A.C., Jones, T.K., Marshall, D.C.W. and Rollason, S.J. 1994. Statistical flood frequency estimation. *Ministry of Agriculture, Fisheries and Food.*

Rees, H. G. and Dixon, J. M. 1994 Survey of hydrometric data provision in Europe. *National Rivers Authority*

Rees, G., Gustard, A. and Spijkers, T. 1994. A review of water research programmes in Europe – flood defence and water resources. *Water Research centre/INRA.*

Robinson, M., Moore, R.E. and Blackie, J.R. 1994. An analysis of 25 years of data from the Coalburn catchment. *National Rivers Authority, North West Water plc and Forestry Authority.*

Robinson, M. 1995. Continuous monitoring of soil moisture. *National Rivers Authority.*

Sene, K., Andrews, A., Moores, J.P. and Parks, Y.P. 1995. HYDATA dissemination 1994/95: summary of work performed. *Overseas Development Administration.*

Sene, K.J. 1995. Migration of data from HYDATA and GRIPS to WAMS. Logical and Technical Specification. *National Rivers Authority, Yorkshire Region*

Sene, K.J. and Packman, J. 1995. ESMD, MORECS and the Wallingford Procedure. *Hydraulics Research Ltd.*

Spijkers, T. and Naden, P. 1994. Data storage and analysis for continuous rainfall-runoff modelling. *Ministry of Agriculture, Fisheries and Food.*

Stewart, E.J. and Reynard, N.S. 1994. Rainfall frequency estimation in England and Wales. Phase 1a: Survey. R&D Note 175. *National Rivers Authority.*

Wallace, J.S. and Jackson, N.A. 1994. Water balance of agroforestry systems on hillslopes. Second Annual Report to the ODA Forestry Programme. *Overseas Development Administration.*

Watts, C.G., Grew, R. and Young, A.R. Predicting artificially influenced flow statistics using Micro LOW FLOWS v2.1. *National Rivers Authority.*

Wilkinson, R. J., Jenkins, A., Wyer, M. and Kay, D. 1994. Modelling faecal coliforms in streams. *Department of the Environment.*

Williams, A. and Gilman, K. 1995. The protection of East Anglian wetlands - Phase 2. *National Rivers Authority, Anglian Region.*

Williams, R. J., Johnson, A.C. and Batchelor, C.H. 1994. Pesticide Briefing Note for Director of European Union DG XII. *Commission of the European Communities.*

Williams, R. J. 1994. Rosemaund pesticide runoff study at ADAS Rosemaund, Report of years 3 to 5. *ADAS, Oxford.*

Wright, I.R. and Gash, J.H.C. 1995. Carbon, water and energy of tropical biomes. Surface conductance and evaporation modelling of Amazon rainforest. *TIGER project. Natural Environment Research Council.*

Young, A.R., Gustard, A. and Irving, K.M. 1995. European atlas of small-scale hydropower resrouces. *ALTENER committee.*

Young, A.R. and Sekulin, A.E. 1994. Software requirements – Phase III. Study into the naturalised flow records in the Essex region. *National Rivers Authority.*

Software development

Bell, V.A., Carrington, D.S., Moore, R.J. 1994. Rainfall forecasting using a simple advected cloud model with weather radar, satellite infra-red and surface weather observations: An initial appraisal under UK conditions. Document HYREX1/IH/1, Version 1.0, December 1994, Institute of Hydrology, 58pp.

Flavin, R.W.1994. EDITDESC User Guide and Manual. Institute of Hydrology.

Flavin, R.W.1994. DGENER8 User Guide and Manual. Institute of Hydrology.

Institute of Hydrology, 1994. HYRAD Version 1.1 System Manual.

Hydrology Software Section, Institute of Hydrology. 1995. HYMERGE: Merging package for HYDATA databases.

Hydrology Software Section, Institute of Hydrology. 1995. SWIPS Version 1.0 system and user manual.

Institute of Hydrology, 1994. HYRAD Version 1.1 User Manual.

Institute of Hydrology, 1994. RFFS Model Calibration Facilities: PDM Rainfall-Runoff Model: User Guide. Version 1.0, Institute of Hydrology, 24pp.

Institute of Hydrology, 1994. RFFS Model Calibration Facilities: A User Guide. Part I - Rainfall-Runoff Models. National Rivers Authority River Flow Forecasting System, IH Technical Note No. 10, Version 3.0, July 1994, 40 pp.

Irving, K.M., Young, A.R., Bullock, A., Gustard, A., Sekulin, A.E. & Kennedy, N. 1995. Micro LOW FLOWS V2.1. Technical manual and user guide. pp66.

Meigh, J.R. 1995. FLOODS software operation manual.

Meigh, J.R. and Zhang, J.G. 1995. FLOODS - Regional flood frequency analysis software.

Micro Low Flows v2.0 incorporating artificial influences.

Moore, R.V., Bonvoisin, N.J., Tilbury, J. and Howes, A.1994. Water Information System Release 1.4, April 1994. Institute of Hydrology.

Sekulin, A.E. 1995. Micro LOW FLOWS v.2.0 incorporating artificial influences.

Sekulin, A.E., Young, A.R. and Irving, K.M. 1995. Micro LOW FLOWS v. 2.0 Beta test version.

Watts, C.D. and Moore, R.V. 1994. WIS Reference Manual for National Power Data, IH/ICL Report, Institute of Hydrology, Wallingford. 251pp.

APPENDIX III
Current research projects

The Institute of Hydrology is a component body of the UK Natural Environment Research Council. Its science contributes to the integrated research programmes of the Centre for Ecology and Hydrology, comprising
Institute of Freshwater Ecology
Institute of Hydrology
Institute of Terrestrial Ecology
and
Institute of Virology and Environmental Microbiology
(see page 71)

Programme 3
Global Environmental Change

Surface and boundary layer measurements, Sahel
Joint fluxes in tropical forests
Understanding SVATS for global modelling
Macromodelling (TIGER III)
Automatic weather station, Wytham site
Hydrological impacts modelling (TIGER IV)
Biome change as a climatic feedback

Tropical rainforest processes
ABRACOS: micrometeorology and climatology
ABRACOS: plant physiology and soils
ABRACOS: Tropical rainforest processes
Application of ABRACOS to planning LBE

Climate change
Climate change and water resources in East Africa
CLIMEX – climate change experiment
Hydroclimatology: atmosphere and hydrology in Europe
EC climate change and water resources

Programme 4
Water Management and Hydrological Extremes

Experimental catchments
Plynlimon water use
Effect of clear felling on upland runoff
Impacts of riparian wetlands on stream chemistry
Water resources and afforestation in Scotland
Fluvial geomorphology
Conservation management of wetlands
Erosion of forest roads
The protection of East Anglian wetlands
Impact of particulate outputs from timber harvesting

Catchment data
Plynlimon data water information system

Hydrological modelling
Real-time forecasting of river flows
Distributed hydrological and hydrochemical models
Yorkshire river flow forecasting system
Development of improved methods of snowmelt forecasting
Storms, floods and radar hydrology
Short-term consultancies in hydrological modelling
HYRAD – Hydrological Radar System
River Soar flood warning system

Consultancy, UK
Minor repayment studies
Sub-surface exploration contracts
Jersey catchment study
River Lavant flooding investigation, Chichester
Resource strategy planning
Pakistan flood course

Consultancy, overseas
Future water supply strategy, APC Jordan
Support services for overseas repayment studies
World Flood Study – Phase III
Review of water resources in Lesotho
Water resource development, The Philippines
Global water scarcity
Hydrological review of the Kafue River, Zambia
Tanga and Morogoro water supply, Tanzania

Surface Water Archive
UK surface water data
Water resources research progress

Flood event modelling
Continuous simulation model for flood estimation
Representative basin database
Hydrological summaries for Great Britain

Flow regimes
Flow regimes in Western Europe
Micro-low-flows
Low flow estimation in artificially influenced catchments
Modelling faunal and floral response
European small hydropower atlas
Southern Africa low flows
Naturalised flows in Essex
UK low flow training course
Ecologically acceptable flows

Storm hazards and hydrological extremes
Methods of statistical flood estimation
Flood estimation methods: training courses
Rainfall forecasts, Cameroon hydroelectric schemes
Rainfall frequency study: England and Wales
Flood response of large catchments
ADEPT - analysis of dependent time-series
Strategy for successor publications to the *Flood Studies Report*
Restatement of FSR rainfall-runoff method
Catchment characterisation for flood estimation
Confluence flood: joint probability

Hydrological software
Software development
HYDATA
HYRROM (hydrological rainfall runoff model)
GRIPS (groundwater information processing system)
QUASAR – VAX-version model
QUASAR – PC conversion
Micro-FSR
FFAP (flood frequency analysis package)
HYQUAL (water quality database)
Software training
HYDATA dissemination
HYDATA for Uganda
SWIPS sales and development
IHACRES sales and development
Micro-low-flows sales
HYDATA – Windows development

Environmental Information Systems

Development of a hydrogeographic database
Water Information System
Redigitising the rivers of the NRA North West Region
WIS for rivers affected by cooling water

Agrohydrology

Small-scale irrigation schemes: collector wells
Management of limited water resources
Low-cost, high-efficiency irrigation
Irrigation using collector wells

Urban hydrology

Urban impacts on flood runoff in medium-scale mixed catchments
Urban drainage in the developing world

Hydrological radar experiment (HYREX)

Short-period forecasting incorporating radar data
Radar-raingauge networks for hydrological use

Programme 5
Land/Ocean Interaction Study (LOIS)

Operational management and preparation for field science
Analytical chemistry
Database/GIS for LOIS data centre
LOIS core modelling
LOIS – remote sensing of river corridors
Instream water quality modelling

Programme 6
Hydrological Processes

Regional scale modelling

FIFE/BOREAS
UK Meteorological Office joint development (MITRE)
A model of seasonal vegetation growth for GCMs
Development of SVAT models in EFEDA
Tundra soil-vegetation-atmosphere climate interaction

Dryland degradation processes

Plant physiological controls of evaporation
Hillslope flow process study: Zimbabwe
Water resources in the Messara valley

Environmental impact of trees

Environmental implications of trees and land-use systems
Water balance of African lakes
Land-use change, Upper Mahaweli catchment, Sri Lanka
Hydrological effects of short-rotation energy coppice
Water resource modelling for large catchments
Water resources in Southern Africa

Semi-arid zone water balance

Water use efficiency of rainfed crops
Water use by vegetation in the Sahel
Arid zone recharge (SAGRE)
HAPEX II - Sahel: soils
Remote sensing of semi-arid regions
Water balance of agroforestry system on hillslopes
Land-use change and over-exploitation of water resources, Spain

Surface and subsurface processes

Burnham Beeches groundwater feasibility study
Stream hydrograph and storm runoff mechanisms
Continuous monitoring of soil moisture for the NRA
Worton Rectory Farm groundwater investigation
Analysis of Coalburn catchment data
Herbicide degradation in the sub-surface
Development of a consistent procedure for groundwater estimation
Effect of forestry on summer baseflows

Remote sensing

European Space Agency ERS-1 mission
Application of remote sensing to hydrology
Evaporation input for GCMs from satellite data
EC - ASEAN regional remote sensing, ERS-1

Programme 11
Freshwater Biology and Water Quality

Water quality

European network of catchments
Pesticide pollution in catchments
Acid waters monitoring network
Organics in the aquatic environment
Critical loads of sulphur and nitrogen
Nepal research project
Modelling *E. coli* concentrations in streams
Environmental change in ecosystems
Nitrogen module for MAGIC
Fate of pesticides in unsaturated/saturated zones
Biodiversity in the Himalaya – Darwin Initiative

Hydrochemistry

Forestry impact on upland water quality
Identifying hydrological flow pathways, Spain
Assessing hydrochemical flow pathways
Hydrochemical process studies – TFS/BGS

Programme 13
Scientific Services

Hydrological instrumentation

Capacitance probe
Automatic weather station
Field instruments
Maintenance and development of Hydra equipment
Soil laboratory physics equipment pool and services

ODA coordination

ODA programme coordination
IAHS/ODA UNESCO funding
HOMS activities
Information and dissemination activities
ODA hydrological adviser
ODA Resource Centres Scheme

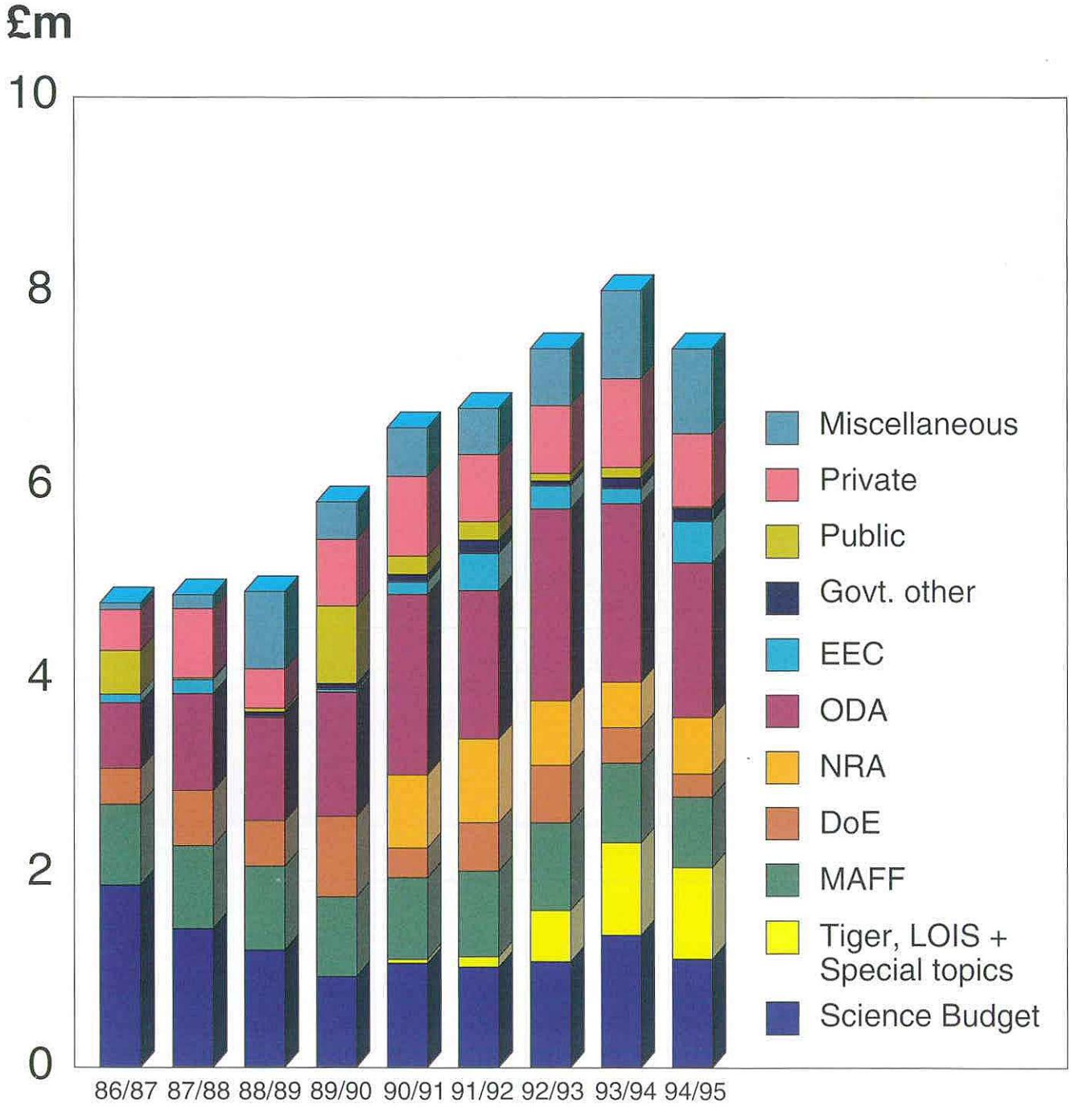
Hydrochemistry laboratory

Chemistry laboratories
Acid waters central chemistry
Environmental isotopes

APPENDIX IV
Finance

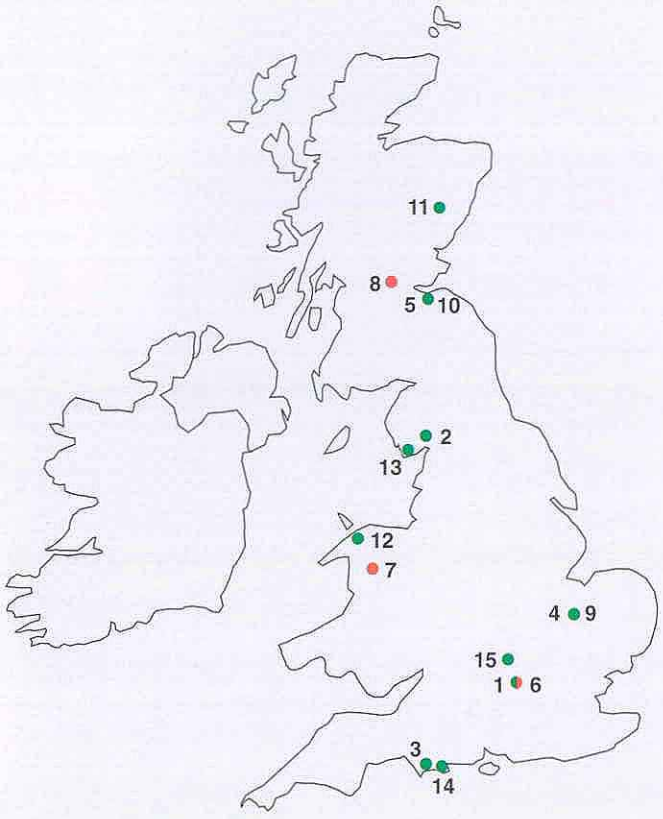
Sources of income

The histogram shows the sources of the Institute's income over the past eight years, adjusted to 1994/95 prices



APPENDIX V

The NERC Centre for Ecology and Hydrology component institutes



Centre for Ecology and Hydrology (CEH)
1. Wallingford

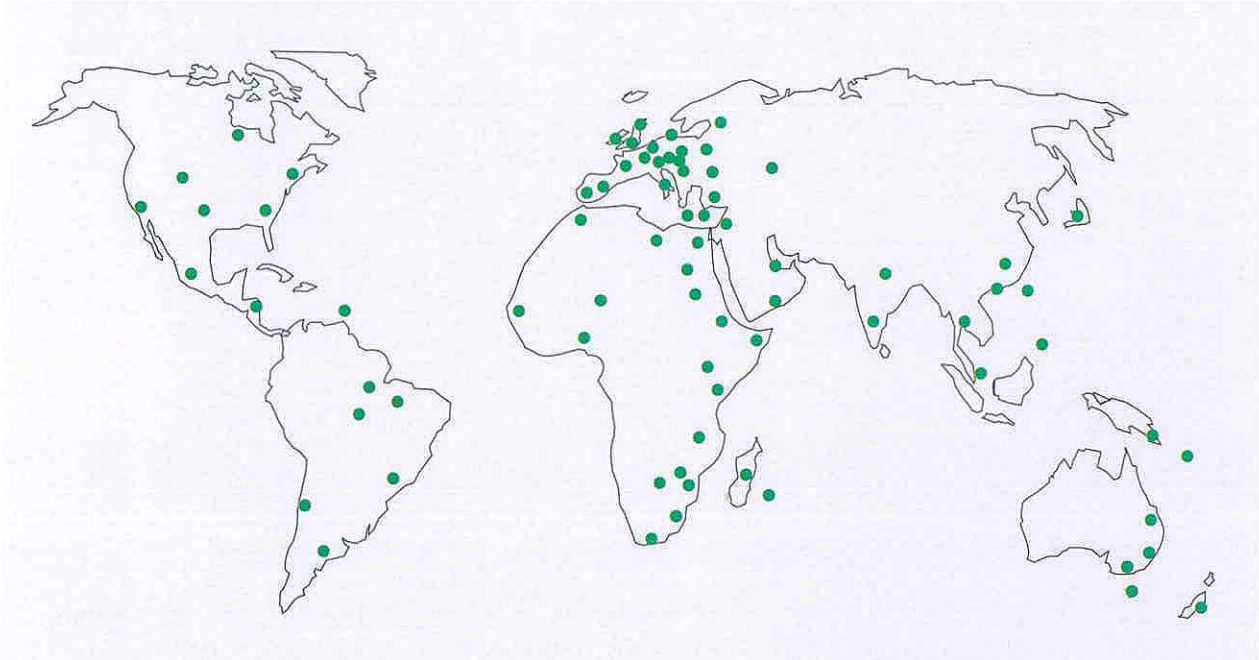
Institute of Freshwater Ecology (IFE)
2. Windermere
3. Wareham
4. Monks Wood
5. Edinburgh

Institute of Hydrology (IH)
6. Wallingford
7. Plynlimon
8. Stirling

Institute of Terrestrial Ecology (ITE)
9. Monks Wood
10. Edinburgh
11. Banchory
12. Bangor
13. Merlewood
14. Furzebrook

Institute of Virology and Environmental Microbiology (IVEM)
15. Oxford

Locations of recent research contracts undertaken by CEH institutes



Centre for Ecology & Hydrology

ISBN Number 1 85531 153 4

Institute of Hydrology
Wallingford, Oxon OX10 8BB, United Kingdom
Telephone: (+44) 1491 838800 Fax (+44) 1491 692424
Email:hydrology@ioh.ac.uk